Exploring human-environment interactions and their effects around Ngel Nyaki Forest Reserve, Nigeria

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List of Abbreviations

ANPP – Annual net primary productivity

BD – Biodiversity

DBH – Diameter at breast height

FR – Forest Reserve

GG – Gashaka Gumpti

GGNP – Gashaka Gumpti National Park

GIS – Geographic Information System

GLCF – Global Land Cover Facility

GPS – Global Positioning System

IBA – Important Bird Area

LCC – Land cover change

LUC – Land use change

LULC – Land use and land cover

LULCC – Land use and land cover change

MAB – Man and biosphere

MDG – Millennium Development Goal

ML – Maximum likelihood

MLC – Maximum likelihood classification

N – Naira

NCF – Nigerian Conservation Foundation

NMFP – Nigerian Montane Forest Project

NN – Ngel Nyaki = Ngel Nyaki Forest Reserve

NNFR – Ngel Nyaki Forest Reserve (including Ngel Nyaki forest and Kurmin Danko forest)

NP – National park

NRM – Natural Resource Management

NZD – New Zealand Dollars

PA – Protected area

RSPB – Royal Society for the Protection of Birds

TLU – Tropical Livestock Unit

TSFS – Taraba State Forest Service

UNEP – United Nations Environmental Program

WA – West Africa

Abstract

Many protected areas around the world face degradation in the face of poverty, maladapted agricultural practices and population growth in their surroundings. This research uses a multidisciplinary approach to study this complex problem in the context of a montane ecosystem. The study area comprises Ngel Nyaki and Kurmin Danko Forest Reserves on the Mambilla Plateau in Eastern Nigeria and the surrounding landscape, comprising pastoral lands, farmland, villages and homesteads.

Ongoing degradation of the Forest Reserves through their illegal use as grazing areas by the local Fulani pastoralists indicates that the exclusionary protection of the forest is not working. It may be that a participatory forestry approach to conservation would be more successful. The research presented in this thesis uses a variety of methods (interviews, remote sensing, geographic information systems (GIS) and ecological monitoring) to evaluate the current situation in the study area with the aim of determining the likelihood of such a participatory approach to conservation being successful.

Satellite images from the years 1988, 2000 and 2009 were used to quantify changes in forest cover to measure deforestation and regeneration rates. Interviews were used to understand the Fulani's pastoral management systems, land ownership status, cattle movements and living situation. Data from interviews and observations as well as from satellite imagery were combined in a GIS to approximate stocking rates and property boundaries and to identify the level of livelihood diversification the different Fulani families have undergone. As grass and water availability have been identified as the main environmental factors determining grazing and cattle movements, environmental data was collected to determine changes in the rates of grass productivity and streamflow over the course of one dry season.

The study found that the extent of natural forest is decreasing all over the study area, on privately owned properties, commonly owned properties and in the Forest Reserves. Evidence of human impacts such as charred grassland by late burning and cattle tracks were clearly visible throughout the reserves, with the exception of the core forest area, indicating ongoing intensive use and management of the reserve for cattle grazing. The stocking rates in dry and wet seasons have been found likely to exceed carrying capacities, which results in overgrazing and a reduction in vegetation cover.

The Fulani in the study area have already undergone a transition from relying purely on livestock and livestock products to relying on a mix of livestock, agriculture and silviculture. This transition shows potential for forest transition according to the 'forest transition theory', which, supported by the right policy incentives could be transformed into landscape scale conservation of endemic flora and fauna.

Biomass productivity and water availability in wet and dry seasons were found to be highly asymmetric, which seriously restricts the number of suitable cattle management systems.

Data indicate that tall riverine vegetation may have effects on stream water availability during the dry season. The findings of this section point to the need of carefully reassessing the current management of tall riverine vegetation on the Mambilla plateau, also in view of the sustainability of the water supply for pastoral livelihoods.

Chapter 1: Introduction

All over the world, natural areas are being converted to areas of human use, such as pastures, cities, towns or agricultural lands (Alemayehu *et al.* 2009). As the global human population grows in number and wealth, the greater is humanity's demand for natural resources. The result is that more and more natural resources and natural environments are appropriated by humans, and production systems on land already managed for human use are intensified (Alemayehu *et al.* 2009). This, in brief, has been the relationship between humans and nature throughout the 20th century with the exception of relatively few protected areas that were set aside to preserve a certain ecosystem or certain rare species. The awakening of the public mind to the dangers of global climate change over the last decade and the general deterioration of the earth's natural environments (MEA 2005) has re-fuelled the ongoing discussion of how to effectively face these environmental predicaments. Scientists and policy makers from a wide variety of disciplines are working on developing methodologies to create win-win situations in which human living standards can be improved while still protecting the natural capital that human welfare depends on (Roe *et al.* 2003; Kaimowitz & Sheil 2007).

This interest is fuelled by the sentiment that in many instances, especially in the developing world, the status quo in environmental protection is neither fair to the local human population (Brockington 2004) nor does it offer adequate protection of biodiversity (Dudley *et al.* 1999). A protected area that exists on maps and legislation but due to lack of effective management is unable to halt environmental degradation has been termed a 'paper park' (Dudley & Stolton 1999).

Bruner (2001) found the degradation of protected areas (PAs) to be a global phenomenon and argues that although protected areas in general are successful in preventing some illegal activities within PA boundaries (e.g. logging, farming), they are less effective at preventing others (e.g. poaching, grazing). This problem of environmental degradation in game or Forest Reserves is not unique and often linked to an unwillingness or inability of governments to enforce regulations in protected areas (Campbell 2002). This situation has in many instances lead to a state of environmental degradation, which is much the same inside the reserve as outside (Dudley *et al.* 1999). The negative impacts of protected areas on local communities and their inability to halt environmental degradation has sparked a passionate argument over how parks and reserves should be managed to improve their track record of social impacts and conservation effectiveness.

Although protected areas of West Africa generally display much higher biodiversity (BD) and natural vegetation inside the reserve boundary than outside (Joppa 2008) (and hence can be considered effective at preserving BD), this is not always the case. Ngel Nyaki and Kurmin Danko Forest Reserves[1], the focus of this paper, is a classic 'paper park': a gazetted and demarcated area that is only nominally under governmental protection from resource exploitation. Although it was created as a Forest Reserve in 1969 to protect endemic plant species and wildlife, little is done to ensure this environmental protection objective is met. At its creation, local people were evicted from within its perimeter in 1969 and hence further wood extraction, clearing and farming was prevented. However, poachers are still active throughout the reserve, and many herders graze their cattle up to the core forest areas, which together contributes to the continuing depletion of wildlife and the retreating forest cover.

In this thesis the natural and cultural landscapes in which Ngel Nyaki and Kurmin Danko Forest Reserves are incorporated are studied in order to understand the sources of conflict between the Fulani pastoralists and conservation goals. Ngel Nyaki Forest Reserve and its surrounds were chosen as the study area because it constitutes a typical example of a failed protected area in that (a) the reserve was created with relatively little concern about the local population, (b) the reserve is effectively exclusionary in nature, (c) corruption and the unwillingness to engage in active management by the governing bodies lead to environmental degradation, (d) land tenure around the reserve is ambiguous and insecure, (e) the resident pastoralists resist the exclusion and (f) the existence of both, a pastoralist and an agriculturist society in the region, which politicises any undertaking. Some or all of these issues can be identified as important obstacles to successful management of protected areas and neighbouring communities in almost every publication on pastoralist-park conflicts in developing countries. Finally, the Nigerian Montane Forest Project (NMFP), which has strong links to the University of Canterbury, operates a field station in close vicinity of the reserve. It was possible to use this field station as a field base for this research which made the undertaking feasible.

1.1 Placing the research within the existing literature

Frantz (1981) and Hurault (1998) have both described the change of the Mambilla plateau and its people through time, both identifying drivers of change and exploring the interactions between the local tribes. Blench (1984) and Boutrais (2007) wrote extensively about Fulani cattle breeds and pastoral livelihood strategies. Some of their research was undertaken on Mambilla, although most of these types of studies are of wider scope and refer to West African highlands in general. There is some literature on the relationships between the Fulani pastoralists living in enclaves within the Gashaka Gumti National Park, which borders the Mambilla plateau (Dunn 1994). A recent study has recapitulated the effects that the creation of Ngel Nyaki and Kurmin Danko Forest Reserve had on the local farming population living around the perimeter of the reserve (MacDonald 2007). Another study has explored the

[1] In Nigeria, National Parks are managed on a national level, which means the park is under protection of the federal government and has the highest level of protection. Forest Reserves in Nigeria are dually managed by the relevant state government and local authority and have a lower protection level than National Parks (Federal Department of Forestry 2001).

livelihoods and natural resource dependency of Yelwa village. The village was founded by the displaced families from the former Ngel Nyaki village, which was located within the reserve boundaries when Ngel Nyaki was declared a protected area (Korndoerfer 2010). However there has been no study into the activities of the Fulani pastoralists living around Ngel Nyaki Forest Reserve and who are the only local group that are using the reserve on a day-to-day basis. In addition, their activities have been identified as the main threat to conservation success in the reserve. Hence, the focus of this work is to shed light on the livelihood strategies of the Fulani in this region and their motivations to use the reserve and thus aid the sustainable management of the Ngel Nyaki Forest Reserve.

1.2 Purpose of Study

The purpose of the present study is to increase our understanding of the land-use in and around the Ngel Nyaki and Kurmin Danko Forest Reserve and the effects this land use has on land cover (particularly forest cover). The dominant land-use is cattle grazing by local Fulani land owners. An improved knowledge base about the Fulani livelihoods may enable a more effective and sustainable management of the protected area. Important aspects of Fulani livelihood generation, that were considered likely to affect their impact on the reserve, included the local environmental limitations to grazing, the current animal and pasture management systems and the tenure and migration locations of the pastoralists.

1.3 Thesis Approach

This thesis seeks to contribute to the knowledge base pertaining to the study site in four main areas:

(1) Surveying land cover and monitoring land cover changes over time

(2) Exploring Fulani animal and pastoral management, focussing on their interactions with the reserve

(3) Exploring spatial aspects of land use in the study area

(4) Identification of local environmental constraints to grazing and cattle rearing

These thesis goals were achieved by a combination of methods. Land cover surveys have been carried out with the help of remote sensing and GIS. A new and comprehensive satellite image of the study area was taken in 2009 and the current landscape classified. Older satellite images with lower resolution from two other dates were available. The three available images were overlayed in pairs to show changes in land cover over time. The details of this process and the results of this work are found in chapter 3 (pp. 51-99).

The second goal, the study of Fulani animal and pastoral management, was carried out through gathering and collating observational and interview data, as is discussed in chapter 4 (pp. 99-130). To achieve the third goal, Land-use data from satellite imagery, interviews and observations was compiled in a GIS, the detail of which is presented in chapter 5. Finally, the fourth goal of this study, the identification of local environmental constraints to grazing, was investigated in chapter 6 via measurement and compilation of environmental factors such as rainfall, streamflow and grass productivity in experimental plots.

This thesis is based around the theory that accurate assessment of human impact on local natural environments can only be successfully studied through compiling local long-term environmental histories using hybrid social and physical research methods (Batterbury, Forsyth & Thomson 1997). An interdisciplinary approach has been adopted in response to the idea that successful management requires careful monitoring and that a comprehensive monitoring program must be multidisciplinary. Such interdisciplinary monitoring systems are costly in terms of time, effort and funds. One solution is to progressively add layers of information over time, according to user requirements (Brandt *et al.* 2002). This thesis aims to provide a foundation layer of knowledge for the study area based on the four areas of research described above (the current land cover and historical changes in land cover, the livelihood strategies of the dominant local user group, local land-use and local ecological limitations to grazing) to which future layers can be added.

1.4 Thesis structure

Section 1.5 of this thesis presents the conceptual background of this study in the form of a literature review: In section 1.5.1, the issue of environmental protection in developing countries and its impacts on local communities is discussed. As was stated in the thesis goals, a multidisciplinary approach is required for successful protected area management. This means that both the local community and the ecology must be considered. A summary of the various approaches to protected area management is included in this section. Section 1.5.2 focuses on examining different pastoral livelihood strategies in developing countries, while emphasizing the implications of these pastoral management strategies on conservation efforts.

Chapter 2 introduces the study site, its geographic properties and its history and explains the significance of this particular reserve for global biodiversity conservation. In addition, the various stakeholders who contribute towards the management of the protected area are introduced.

Chapter 3 addresses the first goal of this thesis– to identify current land cover units and track land cover changes in the study area from 1988 to 2009. This chapter gives an overview of the different land cover features present and the encountered rates of change.

Chapter 4 focuses on the second goal of this thesis – understanding how the Fulani pastoralists manage their grazing. In this chapter the results of interviews with the Fulani and observations of their behaviour are presented and discussed. This includes an exploration of the power dynamics between cattle herders and cattle owners.

Chapter 5 works towards achieving goal three: It builds on the work of chapters 3 and 4, integrating the information given on current land management with the data provided by current high resolution satellite imagery to map current land-use.

In chapter 6 the fourth and final goal of the thesis, understanding the environmental constraints to grazing, is addressed. This is accomplished by a) analysing the changes in grass productivity over the course of the dry season (section 6.1) and b) analysing the results of stream flow experiments designed to identify the effect of streamside forests on base flow volumes during the dry season (section 6.2).

In Chapters 7 and 8 the main results of each chapter are summarised and placed in a broader context. The results are discussed within the theoretical background of the thesis, which is concluded with a perspective on how sustainable conservation may be advanced in this region.

1.5 Theoretical Background

1.5.1 Conservation, development and natural resource management in developing countries

1.5.1.1 Introduction

This chapter lays out the history of nature conservation in the developing world and focuses on the often-irreconcilable differences in approach that can plague conservation projects (Wilshusen *et al.* 2002). A brief overview of traditional approaches to conservation is presented and explanations are presented as to why local communities in developing countries do not readily adopt a western approach to conservation. As the aim of this thesis is to work towards a sustainable conservation solution for the study area, it is important to understand the roots of the different conservation paradigms that lead to the varied approaches available. Much of the argument about how to reconcile development and conservation in developing countries is based around National Parks, which together with Wilderness Areas and strict nature reserves have the highest protection status among protected areas (Dudley 2009). The study area in this thesis however comprises a Forest Reserve, which in Nigeria means lower protection status. Nevertheless, the theoretical implications of such a reserve for the local population are much the same as for a National Park: inside the reserve no wood cutting, grazing, hunting, farming or habitation is allowed. Therefore the following argument is equally valid for National Parks in developing countries as for the Forest Reserve under study.

1.5.1.2 Opposing views on natural resource management (NRM)

Historically a major disagreement among the various approaches to conservation has been over whether to exclude or include local communities in conservation management (Hutton 2005). This argument has been re-examined during the last decade, as the concerns over worldwide biodiversity loss and extreme poverty are competing for the attention of policy makers and funding agencies (Rodriguez, Acosta & Aguirre 2007).

Proponents of exclusive strategies to protect natural areas such as Terborgh (1999b) and Oates (1999) argue for the creation of more strictly protected reserves in which all extractive use is prohibited. Reserves and parks created in this way are usually based on western ideologies in terms of location and management objectives (Anderson & Grove 1989; Wells, Brandon & Hannah 1992). Within this paradigm, local communities are usually seen as irresponsibly overexploiting their natural resources and therefore they cannot be entrusted with biodiversity protection responsibilities. Therefore it follows that they should be excluded from the reserve perimeter and from reserve management.

There are others who claim that local communities (1) do not necessarily overexploit and degrade their territory and (2) that ‘pristine’ wilderness areas are not as ‘pristine’ as commonly thought. From this stance follows that displacing local people because of conservation issues is both unfounded and unnecessary and may impede learning about local environmental realities (Fairhead & Leach 1995; Medley & Kalibo 2007). This view typically sees the persistent coexistence of local communities and some form of natural resource base as proof that western conservation science is not necessarily needed for the sustainable management of the local environment. The suggested information flow is usually reversed; it is proposed that western scientists learn from the resource management strategies of the indigenous population. This stance would of course embrace community involvement in conservation management if formal conservation was to be carried out (Medley & Kalibo 2007).

Of similar opinion are those who strongly object to the continual appropriation of land for conservation purposes, especially in developing countries, as the burden of conservation carried by the local population is considered disproportionally high (Brockington 2002). This stance criticises the negative impacts of exclusionary or fortress conservation approaches on local communities and would seek to give them a voice in management decisions. On the other hand providing some form of compensation to the local communities without including them in decision making processes may be enough to satisfy the concerns of supporters of this school of thought (Western, Wright & Strum 1994; Brockington 2002; Brockington 2004).

Finally there are positions that demand that conservation and the science of biodiversity protection, together with the political and economical clout of multinational conservation and development agencies, should be employed to benefit poor rural populations in developing countries in achieving sustainable ecological and economical development (Alexiades & Laird 2002; Hutton 2005). This of course has to involve local communities somewhere at the management level as the goal of this type of conservation is to provide help for these communities to guide their development themselves while providing the initial funding and scientific knowledge so this can be achieved sustainably, not to the detriment of local ecosystems.

1.5.1.3 The predicament of protected areas in developing countries

1.5.1.3.1 Western scientific approaches to NRM and biodiversity conservation

Biodiversity conservation is undeniably one of the biggest challenges of the 21st century and has been high on the international agenda for most of the 20th century. To achieve this goal, the traditional western approach has been to set up National Parks in areas of high biodiversity. However, some of today’s conservationists see many of these parks as having achieved only limited success in their ambition to protect biodiversity, especially in developing countries: Either by failing to maintain diversity or by relying on too much donor money to be sustained (Songorwa 1999; Roe *et al.* 2003; Hutton 2005). Often, conservation projects are facing difficulties in achieving their objectives, because western conservation methods based on western conservation ideals and narratives are transferred to create protected areas in developing countries that differ considerably in culture, worldview and value systems (West 1991b). One of these narratives[2] has to be the ideal of a "pristine wilderness" that has to be preserved and all human use excluded. This has been the premise on which the creation of the Yellowstone National Park in the 1870s was based and reflects this era's predominant mindset. In the wake of the establishment of Yellowstone as the world's first National Park, many other exclusive wildlife reserves and National Parks have been created all over the world, especially in the biodiversity rich African savannas, habitat for some of the world's last large mammal populations (Ite 2001). In fact, according to a report published by the UNEP in 2003, protected areas encompass approximately 14% of the land mass and an extent of 6.5m km^2 in developed countries and 12% of the land mass but an extent of 12m km^2 in developing countries (UNEP 2003). While the protection of pristine wilderness in National Parks in the USA was congruent with the worldview and value system of communities in that country, local people in countries of the developing world living around such parks often see them as an unacceptable appropriation of land.

The original definition of a National Park as described above is given in West and Brechin (1991b) as:

"A large area:

1. Where one or several ecosystems are not materially altered by human exploitation and occupation, where plant and animal species, geomorphological sites and habitats are of special scientific, educative and recreative interest or which contains a natural landscape of great beauty;

2. Where the highest competent authority of the country has taken steps to prevent or eliminate as soon as possible exploitation or occupation in the whole area and to enforce effectively the respect of ecological, geomorphological or aesthetic features that have led to its establishment."

Needless to say that notions of "habitats […] of special […] interest" and "landscape[s] of great beauty" as in the definition of a National Park, are deeply steeped in culture and social constructs, notably constructs of a western culture in this case. The extension of western influence on developing countries during colonial times gave Europeans the power to alter traditional conservation strategies, which often employed traditional religious institutions to enforce restraint from resource overexploitation (James & Nwomonoh 1994; Ite 2001). It can be argued that by weakening these institutions through a transfer of power to the new colonial administrators and possibly also through increased missionary activities, these traditional means of resource management diminished in importance (Grove 1995; Ite 2001). This is especially true if the new model of resource management is based on a completely different view of the world in religious, social, moral and economic terms.

[2] The sociological term 'narrative' in this instance should make the reader aware of the post-modernist notions that in many instances the seemingly objective 'facts' on which management decisions are based may be quite subjective in reality, which is in itself constructed by the observer.

1.5.1.3.2 Traditional NRM strategies

Many, although not all pre-colonial cultures had very good knowledge of the resources they were using, their relative abundance and the danger of depletion (Wilken 1987; Gadgil & Berkes 1991; Berkes 1999; Holt 2005). Gadgil and Berkes (1991) explain how the perception of their environment affect traditional peoples' attitude towards resource management. A community that experiences their natural resource base to be patchy and unreliable irrespective of exploitation rates wo not be very likely to have developed a strong sense of conservation. Also populations that see their natural resource base as unlimited either through constant territorial expansion or through a belief in technological advances that will take care of any future shortages, will not put great restraints on resource exploitation. Perceiving one's resource base as finite, spatially demarcated and sensitive to resource use patterns, however will very likely foster sustainable use and conservation practices (Gadgil & Berkes 1991). It is a matter for argument however, whether these traditional practices for sustainable resource management are sufficient to ensure protection of biodiversity, which has recently been gaining acknowledgement as being one of the principal issues in modern western conservation science.

There were a variety of traditional resource management strategies practiced by those traditional cultures that did show restraint from natural resource overexploitation

However, it cannot be taken for granted that restraint from resource exploitation automatically indicates a desire for conservation. Restraint from resource use can also be an economic consideration that limits resource use when the costs or effort of further exploitation exceeds the gain and hence no profit can be realised (Gadgil & Berkes 1991). Therefore the context of resource use restraint also has to be taken into account into the analysis of a traditional culture's resource use. If resource restraint in a given traditional society is mainly dependent on economic considerations like cost effectiveness, it is very likely that advanced technologies rapidly bring about the environmental destruction that Terborgh (1999b) describes. If, however the traditional society relies on resource constraint for long-term gain, which protects the resource base, it is likely that sustainable use and conservation will be carried out even with the arrival of new technologies (Gadgil & Berkes 1991).

Table 1-1: Overview of traditional resource management strategies (adapted from Gadgil and Berkes (1991))

Management strategy	Explanation	Restraint for long term or short term gain	Examples
Quantitative maximum hunting/harvesting quotas	Quotas are set above the limit for cost-effectiveness	Long term gain	Huaorani Indians of Ecuador
Abandoning of hunting when resources decline	Harvesting usually until cost-effectiveness limit is reached	More likely short term gain	New Guinea, Canadian Subarctic
Harvesting from a certain habitat ceases when yields drop	Harvesting usually until cost-effectiveness limit is reached	More likely short term gain	Torres Strait
Harvesting certain species is prohibited in certain seasons	Harvesting in certain seasons is either given up because yields are not cost-effective or because populations are known to be especially sensitive during these seasons	Either	India, Torres Strait
Harvesting from a certain habitat / region is prohibited during a particular season or particular years	A shifting sanctuary is created in which populations can recover, either because of conservation or low net-gain at those times	Either	James Bay, America
Restraint from harvesting certain life stages	Breeding birds or critical areas for breeding and feeding may be spared, either because of low yields or to the purpose of resource replenishment	Either, but more likely long term gain	James Bay, America, India
Absolute prohibition to harvest a certain species	Prohibition either because the harvesting is difficult, too dangerous, consumption entails risks or because other species particularly rely on it	Either, but more likely short term gain	Ficus
Regulation to no or very low levels of harvest of certain habitat patches	Sacred ponds, sacred groves etc may be completely spared and may exist for the purpose of guarding against resource depletion	Unrelated or long term gain	
Banning of certain groups of the population from using certain harvesting methods or from harvesting certain species	Strategy could either reflect the power distribution within the society or may be in place to ban certain groups from using a certain resource, because they are perceived to be very likely to overexploit the resource	Unrelated or long term gain	New Guinea, Fanafuti atoll

Often, compliance with these resource use restraints was ensured by embedding the rules on resource use in an intricate belief system firmly rooted in traditional nature religions and a strong sense of place and belonging. A general belief in a 'community of beings' in which humans were seen as an aspect of the wider environment has been well documented in many anthropological publications. Humans and nature were seen as belonging together, as can be seen by the oral histories of, for example, Native American, Inuit and Australian Aboriginal tribes, which tell us of their personal relations with landscape and its flora and fauna (Basso 1996; Brody 2000; Morrow 2002). Resource management has mostly been carried out by negotiation between individuals and a strong traditional institution, including the utilisation of common property resources like access to land and water. Moreover most traditional peoples were living on subsistence production rather than production for the market. This way of life is in stark contrast to the western principles of a global market economy, capitalism, a strong central government, individual property rights and the notion that humans are separated from nature (Gadgil & Berkes 1991; Thomas 1995; Berkes 1999; Holt 2005). With these fundamental differences in worldview the implementation of a western approach to wilderness preservation can be expected to result in severe resistance from local communities from the outset. And this has indeed been the case.

1.5.1.4 The conservation discourse in a modern context

The American model for conservation, which for a long time was seen as the best way to ensure species conservation, has sometimes been termed the "*fines-and-fences*" approach (Wells, Brandon & Hannah 1992) or "*fortress conservation*" (Brockington 2002) approach. In fact, the fines-and-fences strategy has been the dominant strategy of western society led conservation throughout history. In the 1980s and 1990s it seemed that participatory and community conservation projects were replacing the old paradigm, but the mid 1990s already saw a re-emboldenment of protectionist attitudes in what Hutton *et al.* (2005) termed the "back to the barriers movement". Two of the most fervent advocates of a return to the traditional protectionist approaches are Terborgh (1999b) and Oates (1999). The idea to protect nature in pristine "National Parks" under the exclusion of all human activity (except leisure and tourism) is so dominant that it has become the model for nearly all National Parks that we see today around the world (Ite 2001).

Biodiversity preservation in protected areas around the world is severely threatened by encroachment of human settlements, pastoral grazing and poaching (Terborgh 1999b). Currently there are generally two different views of how biodiversity conservation should be dealing with these threats. The first school of thought clings to the old fines-and-fences model while the second school promotes varying degrees of local participation. It is necessary to note here however, that when circumstances made it necessary, some 'fortress' conservation projects have nevertheless tried to engage to some degree in participatory projects (Terborgh 1999a). Vice versa, on closer scrutiny, some failing community conservation projects were identified as clinging to fortress conservation practices after all (Songorwa 1999; Hutton 2005). From this follows that in a number of cases, the line between the two approaches is not always strict but appears blurred. An example showing clearly the significant overlap that fortress conservation and pro-poor conservation can have has recently been published. The study has found that there is significant in-migration into park edge communities (Wittemyer *et al.* 2008). The authors argue that this shows that local populations nevertheless often perceive protected areas as beneficial locations to make a living, which could indicate that even in some of the theoretically exclusively protected parks some benefits (improved ecosystem services or economic benefits) may still spill over to benefit the surrounding population. This may seem to be an encouraging sign that fortress and pro-poor conservation may not necessarily be as divergent as commonly assumed.

1.5.1.5 Towards a fruitful compromise between poverty alleviation and biodiversity conservation

It has been shown in the previous chapters that both, the protection of nature and the needs of the poor that depend on natural resources, have to be taken into consideration for sustainable conservation projects as well as for sustainable development projects. Often win-win scenarios are possible in such projects but when situations of conflicting and irreconcilable goals arise, trade-offs are inevitable. In the case of conservation versus poverty alleviation, these trade-offs can require particularly painful decisions. Adams *et al.* (2004) therefore suggest in such a situation to first clearly identify the management priorities for a particular conservation or development project. Depending on the identified priorities (poverty alleviation or nature conservation) one of four conceptual stances towards conservation is chosen. All stances share the common goal of conserving biodiversity and taking into account the needs of the rural poor to varying degrees (Table 1-2). These stances are put forward to use as a conceptual framework, which may help to clearly articulate agendas and goals. Clearly articulated goals enable proper monitoring and management and thus allow successful implementation of conservation and poverty alleviation projects.

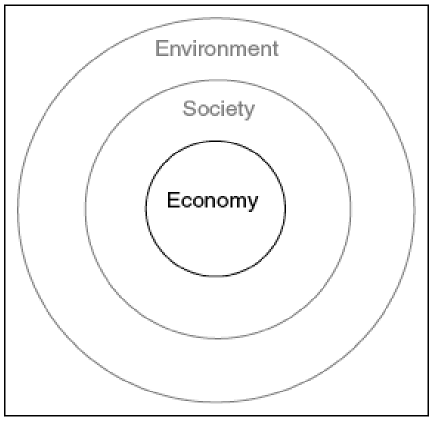
Table 1-2: Overview of different views on the relationship between poverty and conservation efforts

Conservation Stance	Implications for Conservation	Implications for Poverty Reduction	Proponents	Problems
1. Poverty and conservation are separate policy realms	• Goal is to establish and effectively manage a global network of protected areas • Success is measured in terms of species diversity and abundance • Conservation is carried out informed by scientific criteria • If poverty is a cause for conservation failure, more PAs of critical BD importance have to be created and strongly defended	• Poverty reduction benefits indirectly through improved ecosystem services (e.g. watershed protection) or revenues through eco-tourism or direct payments • Local win-win situations can be realised, but a general combination of conservation and poverty alleviation is seen as misallocation of limited conservation resources	(Oates 1999; Terborgh 1999b)	• This approach is easier to manage, given enough funding and does not require highly skilled facilitators for negotiations, therefore other solutions that could lead to win-win situations may not be sought • If not prioritised, win-win situations are not easily found • Authoritative appropriation of land irrespective of local approval will lead to resistance and entrenched positions and thus blocks creative solutions to complex problems • It may not be possible to create enough undisturbed reserves to protect biodiversity
2. Poverty is a critical constraint on conservation	• When poor people cannot be stopped from overexploiting biodiverse land and poverty is identified as the cause for this poverty alleviation is permitted if it helps conservation	• Poverty reduction solely as a means to achieve higher efficiency in conservation • Focussing on people that have the power to disrupt conservation efforts	(Western, Wright & Strum 1994; Barrett & Arcese 1995; Hulme & Murphree 2001)	• People that so far had smaller impacts on conservation may be encouraged to switch to unsustainable practices to get a share of the benefits • Peoples with a smaller impact may be overlooked in the distribution of benefits • May entrench unequal power relations between local groups • Immigration into edge communities may threaten success • Benefits might not flow to the people that actually threaten the environment

				• It is likely that first exclusive strategies are tried and only if these are without success, poverty alleviation is attempted, but then trust within the local population may already be too damaged to provide win-win solution
3. Conservation should not compromise poverty reduction	• Conservation as primary goal • Conservation is seen as having a moral obligation to also concern itself with the local population in their region of operation even if conservation projects are able to be imposed and sustained without local approval	• Conservation agencies ca not impose conservation projects that undermine the livelihoods of the poor • Income generating ventures within PA boundaries and within BD constraints are possible • Sustainable harvesting is possible	(Brockington 2004)	• Creating intervention policies to ensure species survival may not be possible • A prohibiting policy prescription might paralyse policy and management instead of creating an environment of proactive solution seeking
4. Poverty Reduction depends on living resource conservation	• BD benefits indirectly from the conservation of a diverse resource base	• Conservation as a tool to reduce poverty and improve social justice • Sustainable use of resources is encouraged	(West 1991a; Koziell & Saunders 2001; Roe *et al.* 2003; Hutton 2005; Adams & Hutton 2007; Kaimowitz & Sheil 2007)	• Not all BD is needed for good ecosystem functioning and so might vanish • Creating intervention policies to ensure species survival may not be possible

Considering the severe criticisms of the exclusive fortress conservation model in the recent decade (Wilshusen *et al.* 2002; Hutton 2005), it becomes quite clear that conservation agencies have to be socially accountable in regards to the effects conservation projects have on local communities when implementing them in developing countries. Otherwise conservation projects are in danger of losing their credibility as being ethically sound undertakings. What Table 1-2 shows, however, is that this social accountability can be realised in different ways, each with its own set of problems. What can be deduced from the range of problems that stance 1 and 2 pose is that only conservation in a combination of stance 3 and 4 has a serious chance of achieving the Millennium Development Goals (Roe & Elliott 2004) of biodiversity conservation and reducing hunger and poverty in developing countries.

This does not necessarily mean that preserving biodiversity should come second to poverty alleviation in pro-poor conservation efforts. What has been shown time and again is that poor communities are particularly dependent on natural ecosystem services (Roe *et al.* 2003; Kaimowitz & Sheil 2007). It has also been shown that ecosystems are most resilient to disturbances like climate change or severe weather conditions if their diversity in flora and fauna is maintained. Therefore, in order to buffer poor communities for instance from the effects of natural disasters, the protection of biodiversity has to play a central role. This is the argument that proponents of stance 4 (Table 1-2) follow when suggesting pro-poor conservation as a solution to tackle species loss and the eradication of poverty at the same time. This stance also recognises the nested nature of the three sectors that make up sustainable development (Giddings 2002), without falling into the common trap of thinking of the economy, society and environment as separate independent spheres (Figure 1-1).



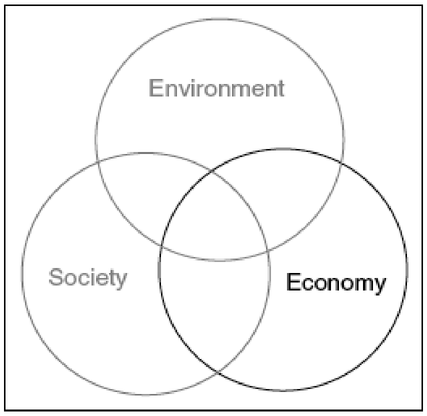


Figure 1-1: Differing views of sustainable development and the three spheres of human activities:
On the left is the nested view, where the economy works within social constraints and the social and economical spheres both are contained within environmental constraints. The picture on the right illustrates how sustainable development is typically depicted, with the economy, society and environment consituting three separate spheres (Giddings 2002).

Central to this idea is the notion that without managing the environment sustainably, it is impossible to create a sustainable society or a sustainable economy. From this follows that if the NRM systems in place are unsustainable,

unsustainable development will follow. Hence, conservation of biodiversity and healthy ecosystems should also be essential goals for poverty alleviation programs. However, conservation efforts that trap surrounding communities in poverty and alienate them from their natural resources will most likely create an unsustainable society and economy, which will certainly handicap the conservation project in the long run.

Reconciliation between protectionist and community conservationist views could spring from Sanderson (2002) who demonstrates that humanity appropriates ca. 83% of the land's surface for its own purposes. From this he draws the conclusion that the "wild spaces" are running out. Keeping this in mind a rule of thumb could be drawn up that seeks to protect 'pristine lands' without a present human population (taking into account the needs of hunter-gather populations, whose area of influence cannot easily be demarcated), fostering sustainable management and stewardship in areas that are inhabited by humans through participatory conservation and restoring natural areas where humanity's domination over nature is complete, namely in the big cities and throughout the industrialised world. This approach has already begun to be put into practice in the UNEP's 'Man and Biosphere' (MAB) programme, where exactly these issues are being addressed. In MAB projects, core areas exist that are exclusively protected, surrounded by zones of differing use (Figure 1-2).

Figure 1-2: Schematic diagram of biosphere reserve zonation

(source: UNESCO 2007 (www.unesco.org/mab/faq_br.shtml)

However, only 564 designated MAB reserves were established by 2010 (UNESCO 2010), while as of 2008 over 120,000 protected areas were listed (UNEP 2010). These statistics show that the biosphere approach as yet only plays a minor role in worldwide conservation efforts and there is a long way to go for this approach to become the dominant one.

1.5.2 Pastoralism

1.5.2.1 Introduction

In one aspect all models of conservation are congruent: They all concern themselves with the human and environmental systems of an area and seek to make effective conservation or sustainable resource management possible. In protected area management it is very difficult to control the access of mobile individuals, such as poachers or pastoralists (Bruner *et al.* 2001). For example the Forest Reserve which is the focus of this thesis suffers from damage caused by the illegal exploitation of the reserve by the local pastoralists and their cattle.

The details of pastoral management strategies vary considerably among pastoralists. The differences between different pastoral groups are highlighted in the following chapter. Also the effects that pastoralist activities can have on the environment and the frequently resulting conflicts between pastoralists and conservationists are explained.

1.5.2.2 Terminology

Pastoralist is a wide-ranging term describing local communities or individuals, where livelihood dependence on animal husbandry makes up more than 50% of the total income portfolio (Sandford 1983; Blench 2001). Pastoralism includes the high-tech, high-input ranches of developed countries in Europe, North America, Australia and New Zealand to the traditional, low- or no-input systems mostly found in developing countries in Asia, Africa and South America. Enclosed livestock production facilities with an industrialised meat production focus, common mostly in developed countries of Europe and North America, are usually excluded (Blench 2001). In this work the main focus is on traditional smallholder pastoralist systems, specifically those of the dry lands and areas of high rainfall variability and it is in this context that the term pastoralist is used.

1.5.2.3 A short history of pastoralism

The dawn of pastoralism dates back some 6000 years and was established from the herding and domestication of wild herbivores (Blench 2001). Many scholars are of the opinion that the shift of some peoples from agriculturist and agropastoralist towards specialised pastoralist societies occurred under the pressures of a growing and increasingly settled population where space limitations drove people to graze their animals further and further away from urban centres and their intensified agricultural production systems (Lees 1974). This would in part explain the absence of traditional pastoralist systems in Australia and North America because these areas have had a relative low population density throughout history.

Mid-density populations in conjunction with wide empty rangelands are thought to have favoured the emergence of pastoralism while low-density populations encouraged the persistence of hunter-gatherer livelihoods (Lees 1974; Fall 1998; Blench 2001).

Pastoralists, who are leaving an expanding agriculturalist society behind in favour of unclaimed grasslands where it is possible to find enough forage for an increasing herd size, do not completely abandon the original society. All over the world pastoralists have developed intricate networks of trade and negotiated access to forage with the settled agriculturist societies they encounter. An enormous advantage for pastoralists, especially for nomadic pastoralists, is that they are able to produce animal protein from marginal land in areas where the climate is either too hot, too dry, too cold or too unpredictable for arable farming (Oba & Lusigi 1987; Blench 2001). Even today, pastoralists provide a significant amount of animal protein and other animal products to their host communities and contribute considerably to the national economy. Their relative contribution in developing countries is even higher than in developed nations, although the exact contribution is difficult to quantify (Blench 2001).

1.5.2.4 Modes of pastoralism

Pastoralist systems can be analysed according to several different aspects: the species used, the management system in place, the geography in which the system is embedded and the ecology on which the system depends.

Although having basic livelihood strategies (raising and tending to animals) in common, pastoralists show a diversity of approaches to meet their specific needs. Blench (2001) suggests several aspects by which pastoralists can be classified. The classification criteria are summarised in Table 1-3.

Table 1-3 Classification matrix adapted from Blench (2001)

Classification Criteria	Strategy	Explanation	Category
Mobility	Nomadic	Patterns of movement vary from year to year, no fixed homestead	A
	Transhumant	Seasonal horizontal or vertical movement of herds in fixed patterns, fixed homesteads	B
	Settled	Fixed homesteads, land rights for farms	C
	Ranching	Usually fenced ranching systems, land rights for pastures, fixed homesteads	D
Species	One	Only one species is raised and herded simultaneously	E
	Many	Many different species are raised and herded	F
Dependency	Full	Only animal husbandry, no agriculture practised	G
	Partial	Agropastoralism, Agriculture practised for subsistence or partial subsistence	H

1.5.2.4.1 Nomadic Pastoralism

The nomadic lifestyle makes it impossible to engage in agricultural enterprises as they have no fixed land holdings. Therefore nomadic pastoralists are totally dependent on trade with communities on their migration route to whom either individual animals or animal products are sold or exchanged for agricultural produce. Often agricultural communities are eager to trade the animals' manure in exchange for access to the farmers' crop residues (Bassett 1988). Generally the nomads have negotiated access to pastures or forage resources and established extensive and complex social and economical networks with the communities along relatively fixed migration routes. Along these routes the pastoralists have sound knowledge of markets, pasture, rainfall, diseases, the political situation and national boundaries (Blench 2001). Categorised in the manner given in Table 1-3, nomadic pastoralists always fall into categories A and G, while they may depend on only one or many species (E,F) for their subsistence. Nomadism is practised mostly in arid environments with unreliable rainfall. It allows the opportunistic exploitation of scarce and scattered forage, such as short lasting localised green flushes after a brief spell of rain.

1.5.2.4.2 Transhumant Pastoralism

Blench (2001) defines transhumance as "the regular movement of herds between fixed points to exploit seasonal availability of pastures." This movement can be vertical or horizontal. Vertical movement is important in mountainous regions where heavy snow cover during the winter months necessitates the migration to lower altitudes. The range is usually divided into summer and winter pastures. Horizontal movement is most common in seasonally arid and semi arid environments with high *inter*seasonal but low *intra*seasonal rainfall variability (Blench 2001). In this case the main environmental driver behind the movement is seasonal forage shortage due to a lack of rain. Additionally, water availability and therefore seasonal herd migration, is often associated with the spread of disease vectors, such as the Tsetse fly (Omotayo 1999). This is the common pattern observed in West Africa: Pastoralists take their animals south in the dry season, when forage is available and disease threat through insects minimised. In the wet season the rain front penetrates areas much further north and so the herds move north again where humidity related diseases are less and forage readily available yet again (Blench 2001). Transhumant pastoralists often split their herds according to their needs. In communities where some members such as people of old age or mothers with young children are staying behind a few animals are usually left for them at the homestead. The kind of animals left behind depends on the individual group's needs. Some groups leave lactating animals behind to support their families with milk and milk products, some leave weak animals that are not fit for migration while others leave work animals (Blench 2001).

Many transhumant pastoralists are also engaged in limited agricultural production. The fact that every year they spend a significant time at a permanent homestead makes practising small-scale agriculture feasible. This being said, agriculture practised by pastoralists is usually only for subsistence purposes and seldom for the market (Blench 2001).

1.5.2.4.3 Settled Pastoralism

Most settled pastoralists are agropastoralists. They hold land rights over their farms and usually produce enough crops on their land to feed their families. Often their livelihoods are supported by sales of agricultural products but sales of livestock and livestock products still comprise the dominant source of income. Their pastures are usually under communal tenure where they hold grazing rights. The pastures usually do not extend further than a herd can travel in a day. Although settled pastoralists do trade their animals or animal products for currency or other foodstuffs, their livelihood still has a strong subsistence character, which separates them from commercial ranchers (Blench 2001).

1.5.2.4.4 Ranching Systems

Traditional pastoralism usually falls into category A, B or C. Ranching is a form of modern pastoralism and widely observable in North America, Australia and New Zealand. Ranchers hold land rights over the whole extent of their pastures. Hence it is common for ranches to be enclosed systems often demarcated with fences or natural features such as streams, ridgelines or tree plantations along the boundary. Although grazing locations can vary depending on rainfall (e.g. Australia) or the level of the snow line (e.g. New Zealand), usually the owner lives at a fixed homestead and does not move with his animals. The ranch is usually highly specialised on a certain animal product output (e.g leather, beef, milk, wool) and the animals are usually raised only for the exchange value of their products with no or only a marginal subsistence character (FAO 2002).

1.5.2.4.5 Species Specialisation

Another way of categorising pastoralists is by specialisation. Depending on the availability and suitability of species, different groups of pastoralists have specialised on a certain species (e.g. cattle) or even a certain breed within a species (e.g. zebu cattle) as their main livelihood. Some pastoralists co-manage a number of different species (e.g. cattle, goat, sheep, geese) with each of the species contributing to a greater or lesser extent to their livelihood portfolio (Blench 2001).

1.5.2.4.6 Livestock Dependency

Pastoralists can also be categorised by their dependency on livestock, which is closely linked to their mobility and management strategies. From category A to C the livestock dependency decreases as agricultural importance for livelihoods increases. Ranching systems are, at least in developed countries, again fully dependent on livestock (Blench 2001).

1.5.2.5 Conflict and concord between pastoralists and agriculturalists

Depending on the social context and history many pastoralist and agriculturalist communities have developed a love-hate relationship from which both conflict and cooperation may arise (Blench & Dendo 1984; Blench 1996). The obvious concord between pastoralists and agriculturalists is trade of their different products. While agricultural communities often depend on pastoralists for their supply of meat, yoghurt, milk, hides, and other livestock products, the pastoralists require vegetables, grains and other produce from the farmers. Often transhumant or nomadic pastoralists can provide items for trade from far-away regions that they have acquired on their migration. Pastoralists are often also able to trade their animals’ manure for foodstuffs, especially in areas of poor soil nutrition. Access to pastures and crop residues are commonly negotiated between agricultural and pastoral communities (Bassett 1988).

While often the different requirements for the two livelihood systems make for a mutual beneficial relationship between the two parties, there is also potential for severe conflict. This usually arises when migration routes of nomadic or transhumant peoples lead through agricultural land or when cattle grazed adjacent to agricultural land (Bassett 1988; Blench 2003). Hungry cattle can push down fences to eat the crops on the farms, to the annoyance of the farmer. This is generally a problematic issue in areas where the grazing radius of livestock overlap with agricultural land and especially so where the power relations between the two groups are in favour of the pastoralists who then often wo not reimburse the farmer for the damage (Bassett 1988; Hurault 1998).

1.5.2.6 Conflict and concord between pastoralists and conservationists

At different times in the past two opposing views were widespread in the conservationist literature (Blench 2001). One view propagates the romantic view of free pastoralists roaming unwelcoming land with their herds and surviving only through their deep knowledge of nature and the environment. The opposing view holds that pastoralists inevitably overstock, deplete biodiversity and degrade the fragile ecosystems of their environment and so promote desertification wherever they go (Homewood & Rodgers 1987). To successfully understand the role of pastoralism and the resulting threats and opportunities for conservation in a certain area, these generalising myths have to be discarded and replaced by locally adapted research (Homewood & Rodgers 1987).

It is a fact that pastoralists survive in often extremely harsh climates. Additionally, pastoralism as a livelihood means is frequently seen as making the best possible use of sparse or patchy resources on marginal land in these climates. However, it is also held that graziers degrade the land by overstocking and through their frequent burning of pastures. Another grievance for conservationists is that pastoralists are very difficult to exclude from National Parks, as they are notorious for disrespecting boundaries (Blench 2001; Bruner *et al.* 2001).

In many parts of the world pastoralist systems have co-evolved over thousands of years with the local climate patterns and local ecology. The frameworks of many working pastoral systems, however, have changed considerably during the last few centuries. Arbitrarily drawn national boundaries[3] fragmented the landscape and severely restricted the movements of pastoralists (Blench 2001). Also the dramatically increasing population and its demand for animal protein adds to the pressure on pastoral systems. As a result of these changes, many pastoral systems have been pushed into ecological unsustainability (Blench 2001).

1.5.2.6.1 Carrying capacity

The concept of carrying capacity has often been quoted when efforts are made to understand if pastoralists in a certain region pose a threat for conservation. While it is undeniably true that too much livestock on a certain area will eventually degrade the land, the concept of carrying capacity is still elusive (Scarnecchia 1990). As Scarnecchia (1990) points out, there are many different carrying capacities for the same land, depending on the desired management outcomes. Therefore the carrying capacity to maintain a certain type of grassland is much higher than if the management goal is forest regeneration and it also will be quite different between induced grassland and natural grassland. It could then be argued that the carrying capacity should best describe a sustainable harvesting scenario, where the total biomass

[3] Especially in the former colonies

removed per time unit cannot be greater than the biomass produced during the same time unit. However, this calculation ignores possible changes in species composition and hence biodiversity conservation issues.

Estimating carrying capacities in semi-arid climates is especially difficult. There is a significant amount of literature that is in stark disagreement over whether semi-arid environments are especially vulnerable or especially resilient to degradation through grazing pressure (Ellis & Swift 1988). The proponents of the former argue that in semi-arid environments, the biomass production is particularly slow, the fertile soils are shallow and the available flora is under water stress. If grazing pressure is added, the system can easily undergo a change of state and become subjected to desertification (e.g. van de Koppel (1997), Albaladejo (1998), Illius & O'Connor (1999; 2000)).The resilient dry-land hypothesis supporters on the other hand claim that semi-arid ecosystems are limited by the scarcity and irregularity of precipitation and not by grazing pressures. They make their case by quoting empirical evidence of "degraded" semi arid environments that have shown a remarkable ability to quickly return to their former "undegraded" state after periods of severe grazing pressure (e.g. Brockington (2002), Behnke et al (1993), Homewood & Brockington (1999), Dyson-Hudson (1980)).

1.5.2.6.2 Effects of grazing on conservation

As any large-scale disturbance that reduces the heterogeneity of landscapes, intensive grazing can affect biodiversity negatively by subjecting a large area to a single pressure of the same intensity (Fuhlendorf & Engle 2004; Robbins *et al.* 2006). This is especially prominent in unmanaged overstocked pastures, where the same severity of grazing pressure affects the whole area. Managed pastures can be considerably better in terms of biodiversity as grazing pressure can be applied in a patchy fashion. As patchiness of disturbance type and intensity is likely to be one of the critical conditions for high biodiversity it would seem that grazing could indeed be used as a tool for biodiversity conservation, if overstocking is avoided (Fuhlendorf *et al.* 2006).

It has been shown in many studies, that overstocking leads to changes in species composition, facilitates invasion of exotic species, soil compaction, reduced water infiltration, higher run-off and erosion rates, gullying and landslides (Vavra, Parks & Wisdom 2007; Hewitt *et al.* 2010). The four latter aspects are especially prominent in hilly areas with steep slopes. In terms of species composition it can be expected that high stocking rates will particularly favour trampling-resistant and unpalatable species (Hurault 1998). In terms of forest regeneration, high stocking rates are almost always detrimental as young saplings are trampled or browsed although some invasion of woody species can be observed in overgrazed pastures (Hurault 1998). These invading types, however, will not normally be forest species and therefore cannot be classed as proper forest regeneration.

1.5.2.6.3 Effects of fire on conservation

The use of fire as a range management tool is widespread among pastoralists. This can be favourable for conservation if this presents the continuation of a fire regime under which the present ecosystem emerged (Fuhlendorf & Engle 2004). However, if the current human-induced fire regime departs severely from the natural one, a drastic change in species composition is to be expected. Also the extensive use of fire can severely limit natural regeneration as only fire resistant species flourish. In this manner it has been observed that especially grass fires set late in the dry season quickly destroy the remains of a gallery forest in favour of savannah grasslands (Hurault 1998). As human-induced fire regimes often go along with excessive livestock grazing, changes in biodiversity and ecosystem functioning can seriously restrict biodiversity establishment. Also a range of authors believe that adding the removal of plant biomass through extensive grass fires to extensive grazing can quickly lead to overexploitation and degradation of rangelands (Pykala 2005; Mysterud 2006; Anderson & Hoffman 2007; Dufour-Dror 2007; Hambler *et al.* 2007; Mills *et al.* 2007; Yarnell *et al.* 2007; Esquivel *et al.* 2008).

1.5.2.6.4 Boundaries and opportunism

One of the main strengths of the pastoral system is its ability to opportunistically make use of patchy resources over a wide area. This enabled nomadic or transhumant livestock herders to exploit resources in locations that were unavailable to agriculturalists, because of the latter's dependence on persistent favourable conditions in one place (Blench 2001). However with the growing importance of the nation state in local and global politics and a fast growing agricultural population everywhere in the developing world the movement of pastoralists were more and more restricted. Also other land features like protected areas emerged and limited herd movement even further. It may not come as a surprise then that pastoralists are notorious in their non-compliance with artificially drawn boundaries that are diametrically opposed to the requirements of their livelihoods (Blench 1996,2001).

In most pastoral societies grazing decisions are made at the level of the individual, whereas decisions concerning protected area management are made on a regional, national or sometimes even international level (Toutain, De Visscher & Dulieu 2004). Decisions about protected area boundaries are often forced onto the local communities and therefore often lead to the rejection of the reserve as a whole and foster local resistance (Brockington 2002; Brockington 2004; Toutain, De Visscher & Dulieu 2004). Hence the notion of pastoralists as notoriously ignoring official boundaries is born. As Blench (2001) notes: pastoralists' primary objective is to keep their herds healthy and increasing. Unfortunately, increasing compartmentalization of the landscape and human population increases limit their freedom of movement and thus their livelihoods as pastoralist are threatened. Hence pastoralists in many areas are facing a dilemma where no decision leads to a satisfactory outcome: Either, they ignore official boundaries and face fines and prosecution or they lose their traditional way of life and thus their cultural identity (Blench 2001).

Chapter 2: Introducing the Study Site

Ngel Nyaki and Kurmin Danko are currently under the protection of the Sardauna Local Government and are thus classed Local Authority Forest Reserves. They are located on the western escarpment of the Mambilla plateau, Nigeria. First, the general attributes of the environment, such as the geology, climate and vegetation of the Mambilla plateau as a whole are presented, taking into account past reports of researchers to the area as well as observations made during this research period. Then the social history of the region is laid out. Finally, information about the study site in particular is presented.

2.1 The Mambilla Plateau

2.1.1 Location

The Mambilla plateau is an area of undulating hills in eastern Nigeria (Figure 2-1 and Figure 2-2) bordering to Cameroon. Bawden and Tuley (1966) define the Mambilla plateau system to be comprised of "the dissected lava plateau between Mai Samari and Nguroje" with a western edge exhibiting a steep escarpment descending more than 300m. Later the boundary of the plateau was defined by Chapman (2001) as lying between longitude 11º 00' and 11º 30' East and latitude 6º 30' and 7º 15' North (Figure 2-2). The terrain consists mostly of rolling hills with level summits on altitudes between 1500 and 1800m.

Figure 2-1: Google maps image of the location of the Mambilla Plateau in Nigeria (red)

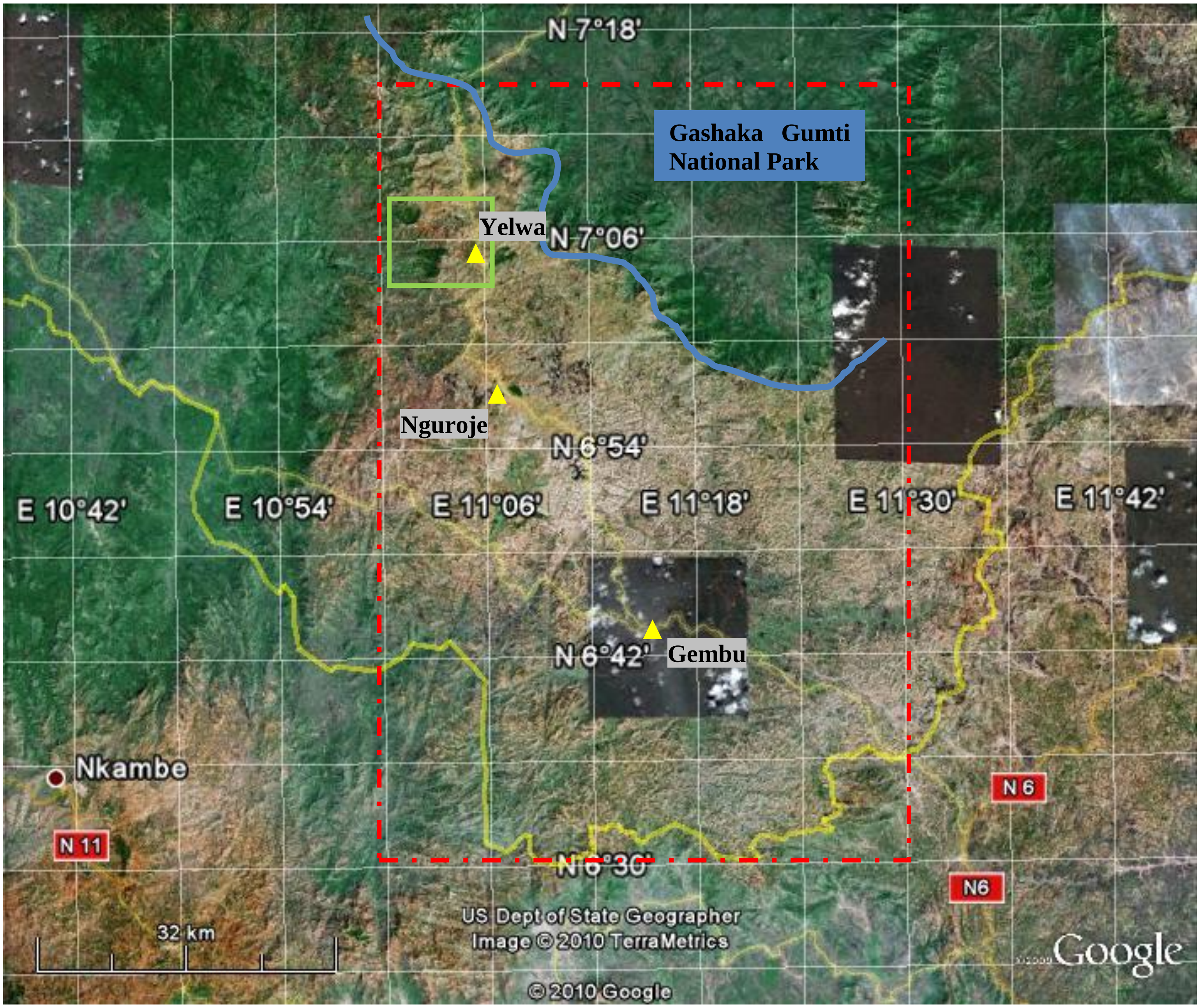


Figure 2-2: Google Earth image of the location of the study area (green) on the Mambilla Plateau (red). The south-western border of Gashaka Gumti National Park (blue) and important towns and cities on the Mambilla plateau (yellow), country borders (thick) and roads (thin) are marked as yellow lines

2.1.2 Soils

The soils encountered on the plateau reach from shallow lithosols on steeper slopes to deeper black alluvial soils on valley floors. On lower grade slopes reddish-brown colluvial soils are prevalent. The soil acidity is given as a pH of 5.6 - 6.0. All soils are heavily leached, although the soils underlain by volcanic rock are slightly richer in nutrients than their basement rock equivalents (Bawden 1966).

2.1.3 Climate

The climate on the Mambilla plateau is defined by its high and reliable annual rainfall despite a pronounced dry season. The wet season usually starts around mid March and typically yields in excess of 1800mm of rain, before in mid

November the rains cease. The dry season correspondingly stretches from mid November to mid March, when often no rain is falling at all (Chapman & Chapman 2001). The daily mean maximum temperatures rarely exceed 30 degrees Celsius, while daily mean minimums at the study site rarely fall below 14 degrees. These figures vary with the seasonal changes on the plateau. The dry season is marked by hot, dry, cloudless days and cold nights, while in the wet season warm humid days and nights predominate with almost daily rainfall (Chapman & Chapman 2001; MacDonald 2007).

2.1.4 Vegetation history

During excursions around the Mambilla plateau during the present field study it was observed that much of the vegetation patterns that Bawden and Tuley (1966) describe (see below) are still valid today. Even single trees on the interfluves have almost vanished completely and natural forests are confined to steep stream embankments and protected Forest Reserves. The remaining streamside forests exhibit dense, shrubby edges with climbing species and vines making the forest edge difficult to penetrate. The protected Forest Reserves Kurmin Danko and Kurmin Ngel Nyaki show similar edge characteristics. The remaining stock of montane forest species on the Mambilla plateau is only found in these reserves, in some remaining riverine forests and in the nearby Gashaka Gumti National Park. The vegetation found inside the reserves comprises montane and submontane forest, guinea savanna, sudan and sahel savanna types, shrubby grassland as well as pure grassland.

Hyparrhenia can only be found in areas devoid of cattle; in the fenced part of the Ngel Nyaki Forest Reserve, on slopes too steep for cattle grazing and close to villages of agricultural tribes. The grassland now consists mostly of *Sporobolus grasses* with annual herbaceous plants partly filling the large inter-tussock spaces in between the *Sporobolus* grass over. In most parts of the grassland, brackens (*Pteridium)* are prevalent between *Sporobolus* tufts and together with shrubby species are visibly encroaching upslope into the grassland from the valley bottoms.

Figure 2-3: Typical dry season scene on the Mambilla plateau. Cattle are grazing the green shoots of *Sporobolus* on a recently burnt pasture.

In 1966 the vegetation on Mambilla consisted mainly of heavily grazed *Hyparrhenia* grasslands with strong evidence of a *Sporobolus* disclimax. The stream banks were already mostly cleared of trees with only a very few remaining on the interfluves (Bawden 1966). A letter from a British administrator, one Major Glasson, confirms that the Mambilla plateau was an area “utterly devoid of trees” already in 1923 (Glasson 1923).

What the dominant vegetation on the Mambilla plateau had been, predating written reports and the colonial era, as well as the processes that lead to its current composition are, however, unclear. Chapman and Chapman (2001) believe that once, long before their studies commenced in 1972, much of Mambilla has been forested, as indicated by soils and altitude, and that most forest destruction was due to farming and burning pressures, especially severe during the 1970s. The destruction of upland forests and riverine forests is seen as endangering the year-round streamflow and protection of lower valleys from flash floods and silting. Hurault (1998), however, provides evidence of a history of a dense tall perennial grass cover on the Mambilla plateau that has existed in this area throughout the Quaternary and has been maintained since through annual burning first by Palaeolithic hunters, then by local farmers. The tall perennial grasses (*Hyparrhenia*) provided a dense vegetation cover that hindered the formation of linear runoff and encouraged non-erosive sheet floods, spread over the whole area. Overgrazing and trampling caused *Hyparrhenia* to recede and make way for the more trampling resistant *Sporobolus pyramidalis* species. *Sporobolus* however exhibits larger inter-tussock spaces of bare soil where linear runoff leads to erosion, hollowing of valleys, gullying and to the development of streams. According to Hurault (1998), the valleys on the plateau had predominantly flat streamless bottoms before the arrival of cattle herds.

Figure 2-4: Removal of vegetation cover leads to erosion and landslides during the wet season.

Surface run-off and erosion levels today must be immense, as given evidence by the ubiquitous signs of erosion: rills, gullies and landslides are visible almost everywhere. The reduction of vegetation cover through overgrazing and annual burning of the grassland is given as a reason for ongoing severe soil erosion (Chapman & Chapman 2001), however Hurault (1998) is of the opinion that the current vegetation is adapted to annual fires and that therefore the decline of vegetation cover can singularly be attributed to overgrazing.

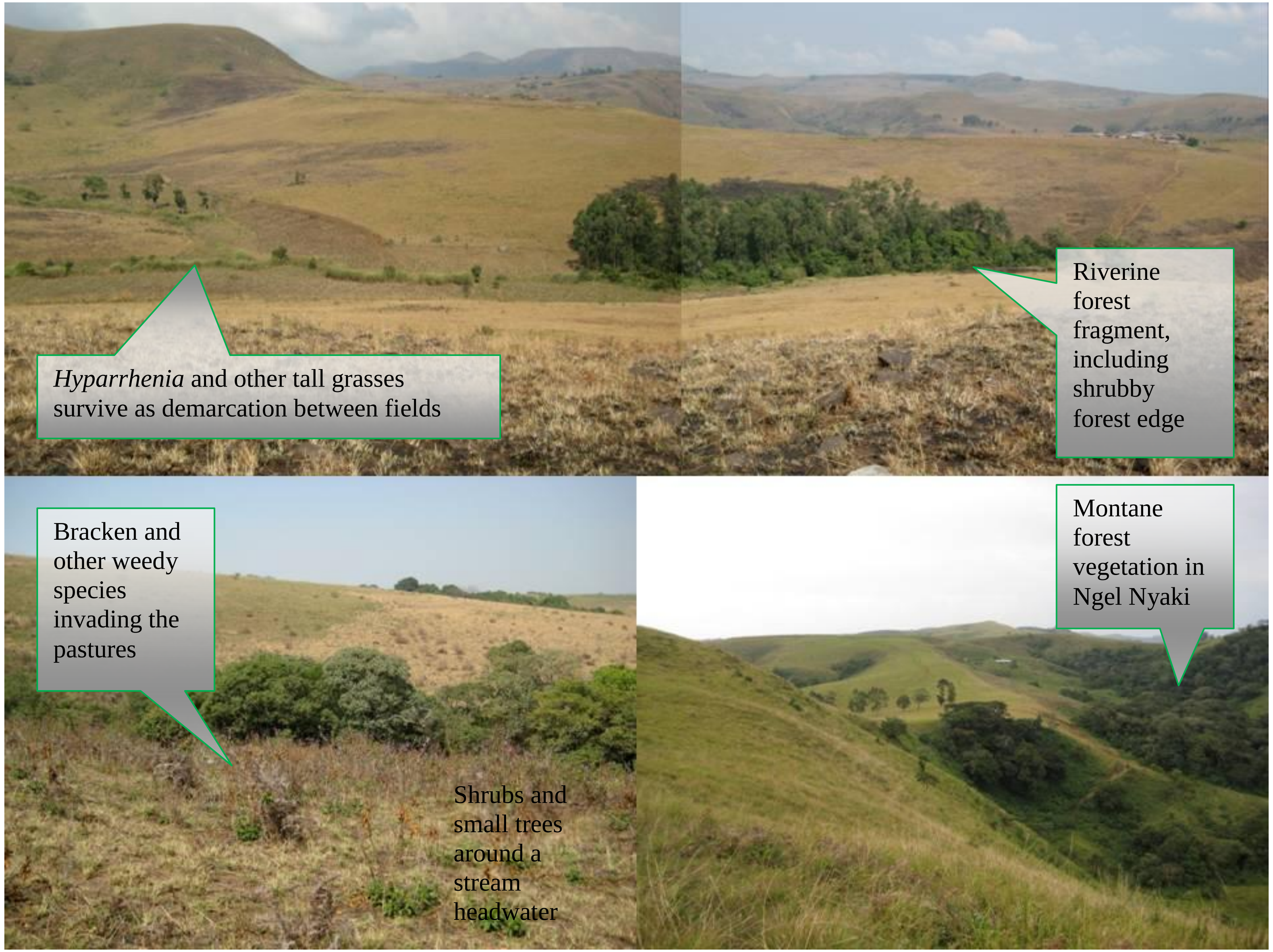


Figure 2-5: Vegetation features of the Mambilla plateau

2.1.5 Social History

2.1.5.1 Time of settlement on Mambilla and the Fulani conquest of the plateau during the 19th century

The Fulani, a traditionally nomadic pastoral tribe, spread from their original homeland in the Futa Toro in the Republic of Guinea and the Gambia River westward over the last millennium (Blench & Dendo 1984). Having converted to Islam they started raiding the Mambilla plateau for slaves and tribute during the 19th century as part of their holy war against non-Muslims, declared by the Sultan of Sokoto. Although the Mambilla tribespeople had fortified hamlets, their military equipment was far inferior to that of the Fulani and so they often were driven from their homesteads and their population was decimated, either through losses from warfare or through introduced diseases. Their population dropped from an estimated 1,000,000 to about 16,000 individuals (Hurault 1998).

It is the commonly accepted history that the Fulani first came to the plateau as conquerors and then as immigrants with the intent to expand their territory and find new grazing areas. At the same time, another tribe, the Mambilla (and other tribes in smaller numbers), had been living there already for an undetermined amount of time and therefore are classed the indigenes of the plateau (Frantz 1974; Frantz 1981; Hurault 1998). According to Rehfisch (1972), an early anthropologist that visited the region in the 1950s, some of the Mambilla groups living on the plateau today migrated there from the lowlands on the Cameroonian side of the plateau around the early to mid 1800s. This would mean that the Mambilla arrived approximately 50-100 years earlier than the Fulani and the other tribes. It is suggested that the early Mambilla immigrants may have been fleeing Fulani slave raids of the lowlands (Rehfisch 1972). This seems like a logical history of the region, however it is in disagreement with the population estimation of Hurault (1998) who puts it to approximately 1,000,000 before the Fulani raids. It seems very unlikely that in these early days the immigration of a few Mambilla groups could have numbered 1,000,000 people and it is impossible for that number to have grown from only a few groups in only 50-100 years. This inconsistency even between the sources generally considered reliable, means that the exact arrival time of the Mambilla tribe is still unknown, and only that the Mambilla have arrived before the Fulani can be noted as a fact.

Yet, this ‘fact’ is still being contested by the Fulani living on the plateau. While the agriculturalist tribes (especially Kaka and Mambilla) claim the title “indigenous” to set themselves apart from the Fulani who are claimed to have come later, the Fulani sources report that the Fulani and the other tribes settled in the area at approximately the same time (Danburam 2004). This dispute can be seen in the light of the ongoing struggle for arable land on the plateau, because those possessing the original land rights are often favoured politically in the distribution and acquisition of land as well as in access to political positions.

2.1.5.2 *The colonial administration of the Mambilla plateau and Fulani immigration*

During the time of German occupation of the plateau (1902-1915), several stations were built as centres of governance and the attacks ceased, but the only graziers that established themselves were in the area around Nguroje (Figure 2-2). The depopulation of the plateau had favoured wildlife to flourish and large mammals like elephants and buffalos, antelopes and warthogs as well as large predators such as lions, panthers and hyenas were numerous (Hurault 1998). The remoteness of the area and the presence of large predators possibly deterred many Fulani from migrating onto the plateau. In fact they did not settle on the Mambilla plateau in large numbers until the 1920s, after the British administrators had taken over the German governance (Hurault 1998). As in most of their colonies, the British preferred indirect rule over the colonised regions and gave the Fulani further control over the plateau. Undoubtedly this was partly due to the realisation that the Mambilla plateau and its climate offer extraordinary opportunities for livestock production. Therefore, efforts were made to repopulate the region with the pastoralist Fulani (Hurault 1998) while at the same time herd movements faced limitations in order to forcedly settle the pastoralists. Because of the previous population collapse, there was ample land for the new immigrants to settle and graze their cattle. The relative political power of the Fulani (who had to answer only to the British administrators) over the remaining Mambilla and other resident tribes was made explicit by the displacement of local tribes by the Fulani who tried to make more room for further immigrants of their own people (Hurault 1998). Also the numbers of cattle owners from the minority tribes and the Mambilla decreased dramatically as the Fulani appropriated first the best grazing areas and later much of the remaining rangeland area (Hurault 1998). Furthermore, in matters of tenure, the increasingly settled Fulani population soon called for conversion of grazing rights in the grasslands into land rights and because of their significant political power in the region most of these applications were granted (Hurault 1998).

2.1.5.3 *Effects of the introduction of the market economy and the monetary system*

With the introduction of a market economy and monetary system by the British in the late 1920s, the area saw a general renunciation of traditional ways to conduct business. While non-Fulani labourers were employed by the Fulani from the beginning of the Fulani settlement period they were at first paid in kind (mainly in milk, meat and calves) (Frantz 1981). With the onset of the market economy the demand for waged employment increased. The Fulani were more than happy to meet this demand. The conducive environment for cattle raising meant that the need for labour soon exceeded the supply available within families (Frantz 1981). This process worked as a social cohesive in this region, because then the Fulani were able to offer employment, instead of manure to engage in the local economy. This was an important factor, as, unlike in other areas where the Fulani settled, on the Mambilla plateau their animal's manure had no exchange value as the local farmers were growing a nitrogen fixing tree (Yom - *Tephrosia vogelii*) that made year round agriculture possible, without application of manure (Frantz 1981). Also the advance of the money economy meant that now the Fulani were better able to buy grain and other foodstuffs as the exchange economy declined (Frantz 1981). On the downside, the advancement of the money economy also encouraged corruption. The official cattle tax constituted most of the district's revenue and hence increased the political influence of the graziers considerably (Frantz 1981; Hurault 1998).

2.1.5.4 Present population issues on the plateau

Today the Mambilla plateau is densely populated by members of different Fulani clans, people from tribes of the Mambilla, Kaka, Ndoro, Panso, Kambu, Tigon and Tiv as well as some Hausa with the Fulani, Mambilla and Kaka making up the vast majority (Frantz 1981; Korndoerfer 2010). The lingua franca is Fulfulde, which can be explained from the history of Fulani superiority, although most people have also retained their own tribal language, which is spoken between members of the same tribe (Fakuade 2003). Many individuals are also capable of speaking the language of other tribal groups other than Fulfulde. Although being the official language in Nigeria, only few people on the Mambilla plateau are able to speak English fluently and most have no English.

2.1.5.5 Levels of literacy among pastoralists and agriculturalists

There is a high amount of illiteracy among the population, even among those who have visited schools (pers. obs.). The levels of literacy and knowledge of English are considerably lower among the Fulani population than among members of other tribes. This may not be surprising, if the history of western education is considered. The fact that historically most schools providing western education in Nigeria and in fact all over Africa were run by Missionaries, with their implicit agenda to convert Pagan and Islamic communities to Christianity, led to many (mostly Islamic) tribes like the Fulani to reject western education altogether (Danburam 2004). Nowadays western education is still viewed with suspicion as the Fulani perceive western schools as a peril to their culture and traditions (Farinde 2008). The circumstance that the Fulani (rich and poor) were a traditionally nomadic people, who due to their constant migrations already have limited opportunities to send their children to a school, removed them even further from western education (Denga 1983; Danburam 2004; Farinde 2008). Conversely, settled pagan communities, such as the Mambilla and Kaka, were mostly converted to Christianity and received western education at the same time (Danburam 2004). As it is a requirement for Muslims to read the Koran, many Fulani visit Koran schools, where they practice Arabic reading and writing, while the Christian communities practice English by reading the Bible and more often than their Fulani counterparts go to regular – now mostly secular – schools (pers. obs.).

2.2 The study area

2.2.1 Location

Kurmin Ngel Nyaki and Kurmin Danko are located towards the north-western escarpment of the Mambilla Plateau. Although Ngel Nyaki Forest Reserve covers an area of approximately 46 km^2, only about 7 km^2 are actually covered by continuous submontane and mid-altitude forest. Kurmin Danko comprises a forested area of 3 km^2, but I was unable to obtain any data on the expanse of this reserve. The reserves are lying between 1400 and 1600m above sea level. They can be reached via a small track from Yelwa village, which is located approximately halfway between Mai Samari and Nguroje.

2.2.2 Significance for conservation

Chapman and Chapman (2001) report that Ngel Nyaki is the most diverse forest on the Mambilla Plateau. This high diversity is mainly due to the abundance of vascular plants, of which many are endemic and near-endemic tree species. Despite its relatively small size, Ngel Nyaki's floristic diversity gives rise to a variety of birds, primates and other animal species. Examples are the Red Data Listed chimpanzee (*Pan troglodytes*), the putty nose monkeys *Cercopithecus nictitans*), the black and white colobus (*Colobus guereza occidentalis*) as well as the white crested Tauraco (*Turacus leucolophus*).

Ngel Nyaki is currently gazetted a Local Authority Forest Reserve under Gashaka-Mambilla Native Authority Forest Reserve Order of April 1969 (Chapman & Chapman 2001) and as such is under the protection of the native (or local) government (in this case the Sardauna Local Government located in Gembu). It has been declared an important bird area (IBA) by Birdlife International in 1999. A detailed report on the importance of this particular forest, it is biodiversity values and the need for conservation has been given by Chapman and Chapman (2001) and Chapman, Olson and Trumm (2004).

2.2.3 Locally active organisations

2.2.3.1 Nigerian Montane Forest Project (NMFP)

In the area two organisations are actively concerned with the reserves' conservation. The first to be introduced here is the Nigerian Montane Forest Project (NMFP), a research institute led by Dr. Hazel Chapman, lecturer in evolutionary biology in the School of Biological Sciences at the University of Canterbury, New Zealand. The aims of the NMFP are:

1. To combine scientific research with education at both tertiary and local community level in order to develop long term sustainable management of Nigeria's montane forests.
2. To facilitate the involvement of national and international researchers in Nigerian montane forest research
3. To involve the community in the management of montane forest ecosystems
4. To work with the community in other ways, such as developing small businesses and working with schools to develop conservation awareness.

(found at: http://www.biol.canterbury.ac.nz/NMF_project/aims.shtml)

Hence, the main focus of this institute lies with the conservation of Ngel Nyaki's biodiversity for research and education purposes. Nevertheless, at the local research field station, the NMFP offers permanent off-farm employment for about 25 men of mixed ethnicity and religion. Apart from income generation these employees have access to English books, magazines and research papers, the station's internet connection and other resources for learning that are hard to find in the surrounding villages. The NMFP is also mentioned in the 2006 annual report of the Darwin initiative, which is stating, that field assistants, rangers and researchers of the NMFP have been working together with the NCF and the RSPB during their visits to Ngel Nyaki and that the pure presence of the NMFP and its researchers and their field assistants helps to protect the biodiversity of the Ngel Nyaki Forest Reserve (Hipkiss & Inahoro 2006).

2.2.3.2 Nigerian Conservation Foundation(NCF) and the Royal Society for the Protection of Birds (RSPB)

The second active organisation in this area is the Nigerian Conservation Foundation (NCF). It is the primary conservation NGO in Nigeria and its mission is:

1. The preservation of a full range of Nigeria's biodiversity which include species, ecosystems and genetic biodiversity
2. The promotion of sustainable use of natural resources for the benefit of present and future generations; and
3. The advocacy of actions that minimize pollution and wasteful utilization of renewable resources.

(found at: http://www.ncfnigeria.org/about.php)

The NCF's main project in the region is the participatory forest management of Ngel Nyaki and other Forest fragments of Taraba State, which started in 2005 and was scheduled to run until mid 2010 in cooperation with the RSPB (RSPB 2010). The aim of this project is to enable the "Taraba State Government and her forest edge communities to manage their biologically diverse forests in a way that is sustainable and that will contribute considerably to poverty reduction in the state" (NCF/RSPB Participatory Forest Management Project Taraba State, Participatory Learning Manual).

On the RSPB website the project objectives have been described thus:

- Developing Participatory Forest Management Plans for 5 forests
- Review and updating laws and regulations that govern forest in Taraba so that the role of communities is recognised
- Establish a network of forest managing communities in the State that will meet regularly and lobby government for an increased role in forest management
- Support alternative income generation activities for communities in return for reducing their dependence on forest products

(taken from: http://www.rspb.org.uk/ourwork/projects/details.aspx?id=tcm:9-208689)

The Darwin Initiative, one of the main donors of the project in the years 2005-2008, mention in their annual report of 2006 the establishment of a women's group, a farmer's group, a grazier's group and a bee keeper's group in Yelwa as part of the participatory forest management project (Hipkiss & Inahoro 2006).

The RSPB website states further the following achievements:

- The Project began in 2005 as a follow up to previous and pioneering participatory management project
- The project works in 5 forest sites and has established a presence in communities neighbouring those forests
- Participatory Forest Management committees have been organised in each of these communities
- The project has been supporting alternative income generation activities in many of the communities through beekeeping training and support, poultry farming, basket and soap making and others
- Draft management plans have been developed for all forests, in consultation with each community
- Incomes are increasing in households that have been supported by the project and there are requests from other communities to expand the project to their forests

(Found at http://www.rspb.org.uk/ourwork/projects/details.aspx?id=tcm:9-208689#achievements)

2.2.3.3 Other groups and societies active in the study area at the time of visit

The women's group and the beekeeper's group appear to be quite successful and more information about these groups, their objectives and successes can be found in Korndoerfer (2010).

During my field research I did not hear of the activities of the farmer's group but I was able to collect some information about two other active associations in the area relevant to this thesis: The Nyakel Dairy Cooperative Society Yelwa (NDCSY) and the Graziers Association Yelwa (GAY). The NDCSY's main objectives relate to milk production, processing and marketing, but also state their interest in the promotion of "the adoption of sustainable ecological and economical agricultural practice among the Yelwa cattle rearers". Other aims include the improvement of the living standards of local traditional graziers, to protect their rights, to care for the health of the local population, to educate on matters of dairying and to organise and arrange for the purchase of modern agricultural inputs (Rules and Regulations – The bylaws of the NDCSY). Interestingly it is also stated in this document that the NCF should advise and assist government bodies to arrange for alternative grazing areas for people affected by the reserve and assist in providing off-farm employment.

The graziers association is also concerned with the promotion of an environment that is conducive to cattle rearing and cattle wellbeing. Also it is stated that the GAY is interested in increasing knowledge about participatory forest management and sustainable management of forests and pastureland. To achieve this goal the GAY is working closely together with the NCF and the RSPB and also other organisations devoted to conservation purposes. Nevertheless the foremost goal is to protect the livelihoods and interests of graziers living in and around Yelwa village (Constitution of the Grazier's Association Yelwa). Interviews on whether or not the GAY is having a real impact on the grazing situation around Ngel Nyaki have been conducted and the results will be discussed in the next chapter.

2.2.4 Contested Forests

2.2.4.1 The problem of dual administration of Forest Reserves in Nigeria

Traditionally the ancestral land was administered by the local chiefs. Under this responsibility fell also the management of forests (Rehfisch 1960; Korndoerfer 2010). With the beginning of the British rule, Fulani elites in the case of the Mambilla plateau, were selected as administrators by the British to whom the local chiefs were subordinate (Rehfisch 1972). This eroded traditional means of accountability of the village chief to his people in matters of forest management. This process was found all over Nigeria in these days (Akinola 2006).

Later, the establishment of a representative local government superseded the native administration, which led to a struggle for the right to exploit forest resources between the old native administration and the new ministers of the local government. The problem of dual control greatly encouraged unauthorised timber felling (Akinola 2006). The Nigerian Land Use Decree of 1978, expropriated land from its original owners and conferred ownership on the executive governor of each state of the federation. As a result, the state governor now had the responsibility for allocation of land in all urban areas to individuals resident in the state and to organizations for residential, agricultural, commercial and other purposes while similar powers with respect to non-urban areas are conferred on Local Governments (Akinola 2006).

When I conducted interviews in the field and attempted to get hold of any official documents pertaining Ngel Nyaki and landownership surrounding the reserve, it became apparent that now there is a power struggle between the Sardauna Local Government and the Taraba State Forest Service, with each side blaming the other for mismanagement, embezzlement and having no real interest in protecting the environment and each side claiming the other side is in possession of the legal documents in question, but would not make it available to me for research. This may not be surprising as natural forests (Forest Reserves) are dually owned by state governments and local authorities. The state forest services have the task of and responsibilities for deciding the level and type of logging activities that may be allowed within and outside the Forest Reserves and hence control the revenue generated (Federal Department of Forestry 2001).

2.2.4.2 Pastoralist-conservationist conflict in Gashaka Gumti National Park

The situation of the pastoralists on the Mambilla plateau immediately affects the management of Gashaka Gumti National Park, which lies at the northern border of the plateau as well as the Ngel Nyaki Forest Reserve, which lies on the eastern escarpment. Therefore I feel it is worth summarising the progression of conflict in Gashaka Gumti shortly as described by Dunn (1994): Containing a large part of Gashaka Gumti National Park, the Taraba State Forestry Service (which was in charge before GG's conservation status was raised from Game reserve to National Park in 1972) has historically pursued a co-operative approach to conservation by directly involving the local Fulani. Areas of grazing and nature conservation have been clearly delineated and the Fulani residing in enclaves within the park boundaries respected them and the ardos (traditional Fulani leaders) discouraged poaching and limited in-migration of newcomers in their area of influence.

During the 1980s the game reserve deteriorated due to diminishing funding and general neglect by the state authorities. When the management of Gashaka Gumti was transferred from state to national authorities in 1991, confusion ensued as to who controlled access to the resources in the reserve. Many Fulani families feared eviction and left the area, the traditional system of access to grazing resources broke down and many herds of cattle migrated into the park from the Mambilla plateau where overgrazed pastures and increased conflict between farmers and pastoralists are prevalent. This led to rapid degradation[4] of the landscape.

Currently, efforts are being made to restore stewardship for the enclaves to existing traditional management institutions. For these institutions to be able to effectively manage the enclaves they have to be supported by legislation that recognises their authority and empowers them to administer sanctions against transgressors of agreed rules and regulations (Dunn 1994).

2.2.4.3 Pastoralist-conservationist conflict in Ngel Nyaki Forest Reserve

On the Mambilla Plateau, the Fulani are in conflict with the Taraba State Forest Service (TSFS) and the Nigerian Conservation Foundation (NCF) over the Protection of Ngel Nyaki Forest Reserve (including Kurmin Danko). In these two protected areas most extractive uses (with some exceptions), farming, grazing and burning were prohibited (MacDonald 2007).

It was not entirely clear whether the participatory framework set up by the NCF and RSPB is planning any changes to this existing policy in the future. So far, the creation of interest groups, alternative income generation and

[4] It should be noted that degradation does not necessarily mean the same thing for Fulani and conservationists. It is quite possible that while conservationists view declining diversity as degradation, Fulani would possibly only recognize degradation as a diminishing ability of the land to sustain their cattle. It is important to realise that there may be a significant difference in constructed reality between researchers and the Fulani pastoralists

awareness raising about the importance of natural forests were the only evident changes made in the management of the region. The outline of the framework promises a concentrated effort to stop pastoralist encroachment (grazing, burning and occupation) on the reserve, however, at the time of research, no signs of this effort have manifested.

As poaching, grazing and burning is illegal and detrimental to the biodiversity values of the reserve, the NMFP has taken on the responsibility of employing rangers to patrol the reserve. However, these patrollers have no legal power. They can only observe and report what they have seen to the NCF and the TSFS. It would be up to these bodies to enforce laws concerning these transgressions, which rarely happens (Chapman 2008, personal communication).

During my field research I often encountered ringbarked trees around herders' huts as well as severe mid and late season fires laid in and around the still existing patches of montane forest inside the reserve. Commercial logging of the reserve was not observed, although paths cut into the streamside forests for cattle to be able to access the streams, were frequently encountered.

The dialogue between the NMFP and the pastoralists in the area has been virtually nonexistent in the past. When this research was started, the NMFP had very little insights into the life, management strategies, the interaction with the reserve and the problems faced by the resident Fulani and as I will show later in this chapter, the NCF's mission of 'enlightenment' has not reached the pastoralists of the plateau either. Therefore it was an important addition to the current knowledge base to obtain an understanding of the Fulani's current animal and pasture management practices and learn where, why and how intensively the Fulani are grazing the reserve. Through this research, the pastoralists may be better incorporated in the participatory forestry framework and their position as important stakeholders is highlighted. On the other hand, as soon as the Fulani are properly positioned within this framework, they will also have to comply with the new management system, which will make a more sustainable management of the reserve possible.

Chapter 3: Land cover and land cover change in the study area

3.1 Introduction

3.1.1 The role of satellite imagery in detecting land use and land cover changes

Humans have always sought to transform their environment to better suit their needs. This ongoing anthropogenic transformation of landscapes contributes considerably to an ever changing pattern of land cover on the surface of the planet with increasingly dire consequences for ecosystem functioning (Vitousek 1997; Turner 2007). Thus it is now widely recognised that assessing and monitoring ecological resources objectively is essential in order to adequately inform policy (Brandt *et al.* 2002). This assessing and monitoring often takes the form of land use and land cover change (LULCC) studies.

While land cover and land use are interdependent, land cover is usually defined as the physical characteristics of the earth's surface (including human built structures, forests, grasslands, etc) (Burley 1961), while land use describes the purpose to which humans put different parts of the landscape (for example as a city, pasture or nature reserve) (Clawson & Stewart 1965; Alemayehu *et al.* 2009). While remotely sensed imagery from satellites or aerial photography can be used to determine land cover, additional sociological and ecological research in the field is often required to understand land use. Conversely, while field studies alone can provide some information about land cover, it has been shown that they are often unable to quantify and analyse spatio-temporal patterns of LULC to the required extent (Liverman 1998; Petit, Scudder & Lambin 2001). In other words, the primary strength of remote sensing (aerial photography and satellite imagery) lies with estimating the extent of LULC and LULCC, while field surveys shed light on the quality of the features concerned as well as on the drivers of LULCC (Brandt *et al.* 2002). Combined, however these two methods are immensely important to predict probable future LULCCs which can be used to inform rural planning and natural resource management (Petit, Scudder & Lambin 2001).

In order to use the potential synergies between field surveys and remote sensing, often the data from both sources are combined in a geographic information system (GIS). One of the main reasons for this is that GIS has proven to be a highly effective tool for visualizing and analysing complex spatial relationships and an experienced user of GIS is able to interpret aggregated data from many diverse sources (Fuller *et al.* 1998; Roy & Tomar 2000; Gottschalk 2002; Mas *et al.* 2004a; Southworth, Nasendra & Munroe 2006; Lele & Joshi 2008).

GIS analyses are often applied in LULCC studies to further the understanding of effects that human land use has on the environment as well as to distinguish natural LULCC from anthropogenic LULCC (López *et al.* 2006; Xiao *et al.* 2006; Shalaby 2007; Antwi, Krawczynski & Wiegleb 2008; Parker, Hessl & Davis 2008; Carrino-Kyker 2009).

3.1.2 LULCC monitoring of protected areas

A specific sub-category of LULCC monitoring is monitoring the effectiveness of protected areas in developing countries. Often this is done through extensive, interdisciplinary LULCC studies (Lung & Schaab 2006). Bruner *et al.* (2001) for example published an interesting meta-analysis of such studies to assess the state and effectiveness of protected areas around the world. Input data to this meta-analysis were datasets produced from questionnaires about "land-use pressure (land clearing, logging, hunting, grazing and fire), local conditions (e.g. presence of human communities in parks and degree of access), and management activities (e.g. number of guards and level of community involvement in management). Several of the reported data in this study are drawn from large scale LULCC surveys around the world (IUCN 1999). Furthermore, measuring the response variable of this study (the extent and quality of the natural environment) is a classic discipline of LULCC monitoring. In the aforementioned IUCN report, especially the disappearance of tropical rainforests and endemic biodiversity in response to land-use pressures was named as the greatest concern.

The role of satellite imagery in successfully monitoring disturbance of tropical rainforests is exemplified by Lung and Schaab (2004). In this study, remotely sensed imagery has been used to detect LULCC of the Kakamega forest in western Kenya. For analysis, a time series of Landsat images (from Landsat 3, 5 and 7) was used covering 29 years in 7 time steps. To define training areas for each of these time steps, amateur air photographs, topographical maps with vegetation information and terrain references have been used. Additionally, for a majority of these time steps, two images per year (one in the dry and one in the wet season) were available, so that the interseasonally changing reflective properties of the vegetation can be taken into account. From this data Lung and Schaab (2004) were able to categorise their study-landscape into 12 different classes of land use and land cover.

In their approach to monitoring protected areas in Estonia, Aaviksoo and Muru (2008) were able to classify Estonian landscapes into 12 different land cover classes. The study relied on Landsat 5 and Landsat 7 imagery of the areas of interest as input data as well as a detailed soil map of the region. The authors argue that IKONOS, Spot 5 or QuickBird imagery offer a much greater potential for accurate vegetation mapping, however these high resolution images are much more expensive than Landsat and are not available from earlier years. In their analysis Aaviksoo and Muru used a transition matrix system described by Singh (1989) to map LULCC. This system allowed a pixel by pixel comparison of land cover at different points in time.

For historical classification, procedures deriving ground-truth information from aerial photographs has been the common strategy in the past (e.g. Ridd 1998). When comparing the suitability of satellite imagery and aerial photography as ground truth material, Brandt *et al.* (2002) conclude that aerial photography used to have more detail than satellite imagery, but that this changed with the advent of IKONOS 1m resolution imagery. This makes QuickBird's 0.6m resolution even better suited for this purpose than IKONOS imagery and provides almost as much detail as aerial photography. In addition, the use of aerial photography is limited to locations were aeroplanes and the required camera equipment are available. These notions imply that the more economical and more widely available option of using satellite imagery can be expected to replace the use of aerial photography for obtaining ground truth information in many future studies (Campana 2002).

Heatwole (2007) pointed out that without adequate groundtruthing of selected training areas (through field studies, aerial photography and/or satellite imagery) for land cover classification, classification results will not be very accurate. Unfortunately, many protected areas are situated in areas that are impassable or for other reasons are missing qualified reference data. At the same time the article highlights the limitations of sensors that only cover wavelengths equal and below near infra-red (NIR) in landscape classification. In order to overcome these obstacles, Heatwole (2007) successfully used very high resolution satellite imagery (QuickBird) for “groundtruthing”, remotely identifying training areas and, subsequently classifying a lower resolution Landsat 7 scene. The use of very high resolution satellite imagery for groundtruthing (analogous to aerial photography) is based on the premise that the classes to be distinguished can be visually discerned on the image or photograph. This way the interpreter has the ability to tell what is actually there, on the ground, in comparison the classification.

The classification described by Heatwole (2007) failed to distinguish effectively between “crop” and “built-up” land cover classes due to the use of straw thatched roofs and earthen roads in the study region. Furthermore the classification showed some confusion of the “wetland” and “forest” cover classes due to the existence of many wet forests at the interface between these two land cover classes. Thus the encountered classification errors are directly related to the specific reflective properties of land cover features in this region. Nevertheless, it proved possible to distinguish 5 different LULC classes (crop & residential, forest, mixed, wetland, water) with an overall accuracy of 82.5% and a kappa[5] coefficient of 74%, when a maximum likelihood classification based on two principal components and a vegetation index was used. When the classification was based on a false colour infrared image the overall accuracy dropped to 66.8% and the overall kappa coefficient to 52.6%. The mediocre classification accuracy of the second method could have been avoided, if the ‘wetland’, ‘forest’ and ‘mixed’ classes had been simplified into one class or a soil moisture sensitive band had been used to distinguish between different levels of ‘wetness’. However, these limitations were due to the spectral data used for classification, not to the method of using pan-sharpened QuickBird imagery to delineate training areas, which yielded sound results in this study.

In a LULCC study by Nagendra *et al.* (2006) the authors decided to simplify their classification of two Landsat 5 images to three land cover classes (non-forest, open forest and closed forest) in order to achieve maximum

[5]The kappa coefficient reflects the classification accuracy corrected for chance agreement between classification and land cover class on the ground

classification accuracy. With this method the authors reported a producer's[6] classification accuracy of 89.5% and a kappa value of $\kappa = 84$ %, which is well within the accuracy targets generally accepted by the scientific community (Foody 2002).

The motivation behind all of the aforementioned studies is that developing an understanding of LULCC (within and in the areas surrounding the PAs) is considered to be of great importance for sustainable PA management. Analysing historical data (e.g. remote sensing imagery, topographic maps and aerial photography) with GIS is essential for this process by providing a tool to explore changes that have occurred in the past, and on the basis of this information predict a probable trajectory of change for the future (Southworth, Nasendra & Munroe 2006).

3.1.3 Deforestation and protected areas

Land use and land cover change has been predicted to be the largest contributor to biodiversity loss and global climate change in the 21st century. As tropical forests are especially important in regulating the global climate as well as harbouring an estimated 60-90% of total global biodiversity it does not come as a surprise that among global environmental impacts caused by LULCC, tropical deforestation is considered to be the single most important culprit (Lung & Schaab 2006; Nagendra, Pareeth & Ghate 2006; Lele & Joshi 2008).

When analysing the main directions of LULCC, land use change from natural landscapes and especially natural forests to productive landscapes for anthropogenic use stands out as the most common direction of land use change globally (Foley *et al.* 2005; Lele & Joshi 2008).

Additionally, such converted areas are often used unsustainably, so that the natural capital of the new non-forest ecosystem decreases rapidly after conversion (Terborgh 1999b), which creates the need to appropriate even more of the natural landscape. Using GIS to detect land use changes early can be a successful way to take corrective measures to landscapes and their use and ensure sustainable productivity (Alemayehu *et al.* 2009). This way livelihoods can be protected, poverty alleviated and the natural capital of a region saved for future generations of all resident species.

3.2 Aims and Goals

The goal of this chapter is to (1) establish an accurate current land cover map from a current (2009) multispectral QuickBird imagery and (2) explore patterns of land cover change between 1988 and 2009 using historical Landsat 5 and Landsat 7 imagery as well as a current (2009) QuickBird image.

3.3 Material and methods

[6] Producer's accuracy is the ratio of correctly classified pixels divided by the total number of *ground truthed pixels* within a class. User's accuracy on the other hand is the ratio of correctly classified pixels divided by the total number *classified pixels* within one class.

3.3.1 Software

All image processing was undertaken using the ArcGIS package, version 9.2. GPS points were downloaded from a Garmin field unit, model GPSMAP®60CSx with the Garmin MapSource software version 6.15.7. The same software was used to edit the GPS data. GPS point tables exported from MapSource were edited with Windows XP Notepad and brought in a format compatible with the ArcGIS software package. In the ensuing work steps, the GPS data were handled exclusively with the ArcGIS package.

3.3.2 Data

3.3.2.1 Satellite imagery

A current high resolution, multi-spectral QuickBird scene of the study area was acquired (Table 3-1) to map current LULC and LULCC. With four available spectral bands (blue, green, red, NIR) QuickBird provides enough spectral bandwidth to easily distinguish between forested and non-forested areas with high spatial resolution (2.44m).

An additional benefit of using QuickBird imagery for this purpose is the very high resolution of 61cm in the panchromatic band. This has been shown to resolve sufficient detail to be used for good visual interpretation of land cover and subsequent classification accuracy assessments (Heatwole 2007). Also small features, and features that cannot be picked up by the classification algorithm, because of their similarity in spectral reflectance, can be visually distinguished and manually digitised (Figure 3-1). The 'remote groundtruthing' approach was necessary because image acquisition was successful only after the fieldwork had already been finished. Aerial photography, another possible source of very high resolution remotely sensed images was not available for this study, due to budget limitations.

Although the high spatial resolution provided by QuickBird also potentially offers the opportunity of object based/ texture based classification (instead of per-pixel classification) this method has not been employed. Object / Texture based classification has been reported to improve classification results in areas of highly heterogenic land cover (such as urban areas) where per-pixel classification accuracy is limited by a narrow spectral resolution of the remotely sensed images. Object / Texture based classification has not been used, because of the satisfactory classification results achieved through per-pixel classification, time limitations and because it was judged to not give considerably better results, due to the homogeneous nature of land cover over the vast majority of the study area (see Wang (2004), Shackelford (2003), Chubey (2006) and Laliberte (2004) for detailed descriptions of object based land cover classification).

Table 3-1: Overview of utilised satellite imagery

Satellite	Sensor	Bands	Resolution	Wavelength [µm]	Acquisition Date
QuickBird	BGIS 2000	Panchromatic	61 cm	0.450-0.900	09/01/2009
		1-Blue 2-Green 3-Red 4-Near IR	2.44 m	0.450-0.520 0.520-0.600 0.630-0.690 0.760-0.900	
Landsat 5	TM	1-Blue 2-Green 3-Red	30 m	0.450-0.520 0.520-0.600 0.630-0.690	02/02/1988
		4-Near IR 5-Mid IR 7-Mid IR 6-Thermal	120 m	0.760-0.900 1.550-1.750 2.080-2.350 10.40-12.50	
Landsat 7	ETM+	8-Panchromatic	15 m	0.520-0.920	03/12/2000
		1-Blue 2-Green 3-Red	30 m	0.450-0.515 0.525-0.605 0.630-0.690	
		4-Near IR 5-Mid IR 7-Mid IR 6-Thermal	60 m	0.760-0.900 1.550-1.750 2.080-2.350 10.40-12.50	

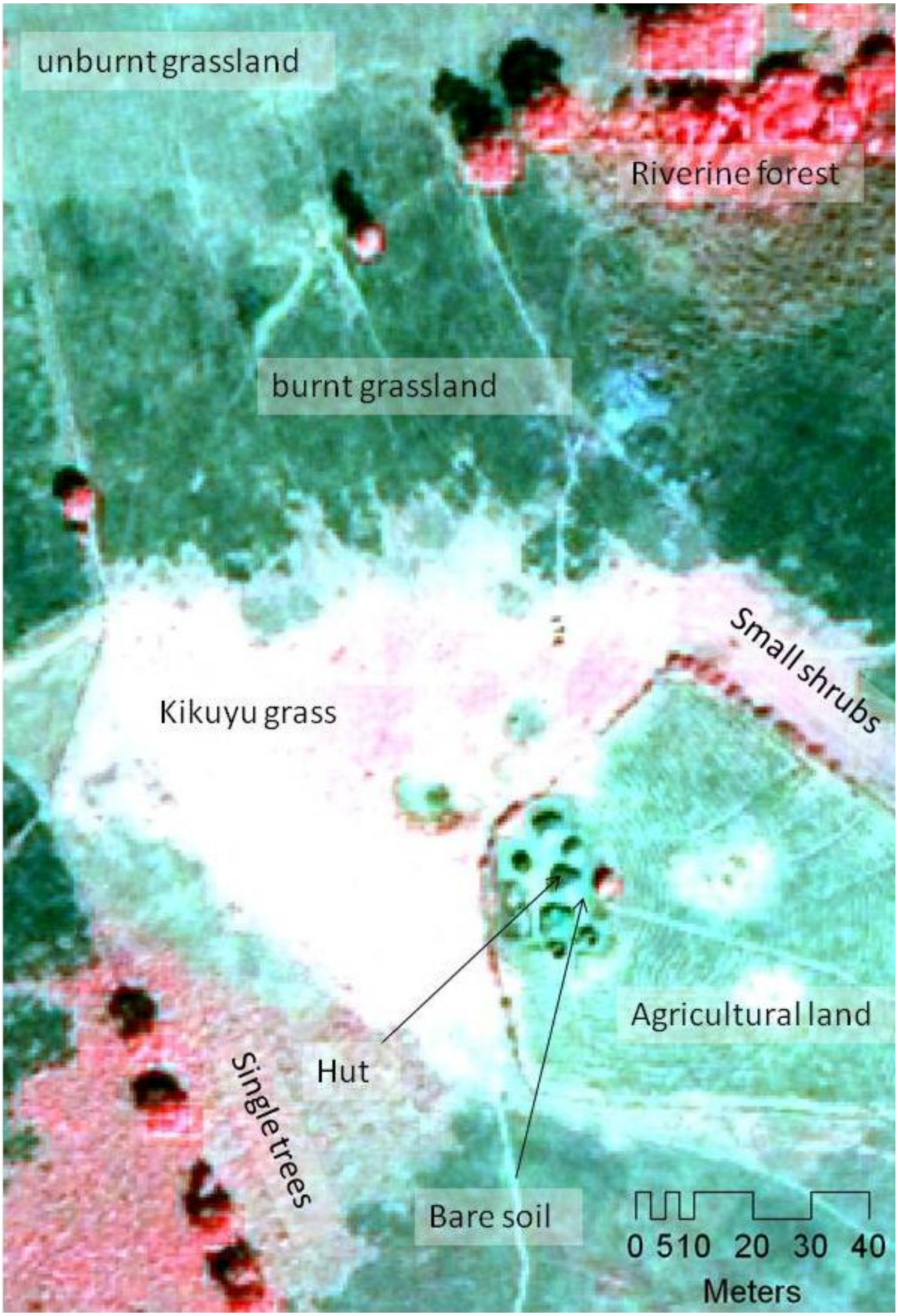


Figure 3-1: Demonstration of QuickBird image resolution

Additionally, two Landsat images were downloaded from the GLCF (http://glcf.umiacs.umd.edu/data). Landsat images have been used in numerous LULCC studies (e.g. DeFries 1999; Lung & Schaab 2004; Mas *et al.* 2004b; Xiao *et al.* 2006). One of the reasons for the popularity of Landsat imagery for LULCC studies, despite their mediocre spatial resolution, is their relative wide spectral range, so that differences in soil moisture and other non-visible reflectance properties can be accessed for analysis. Another reason is the exceptional availability of these images, which can be downloaded free of charge. Landsat 5 has been regularly and reliably recording scenes from 1984 to present, Landsat 7 from 1999 until its unfortunate malfunction in 2003. Nevertheless, the images used in this study (from 1988 and 2000) were the only ones available for the study site through the GLCF web-site. Purchasing additional images from Landsat or other satellites (e.g. Spot or IKONOS) potentially available through other distributors was ruled out due to budget limitations.

The satellite images have all been acquired at near-anniversary dates (mid/end dry season). This means that the vegetation cover should be in a similar phenological state across all three images, which improves the comparability of the three images. All satellite scenes came as georeferenced and GIS-ready GeoTIFF files.

3.3.2.2 Ancillary data

Unfortunately ancillary data for the region is sparse. Only a topographical map of the area from 1960 (scale 1:50 000) was available. The map was digitised using a flat bed scanner with a resolution of 300 dpi. The contour lines were digitised at an interval of 50 ft (15.24 m). The contour lines were used to create a triangulated irregular network (TIN) using the inverse distance weighting algorithm. The finished TIN was further processed to produce a raster of a digital elevation model (DEM). The so created DEM (5x5m cell size) was compared to the 90 x 90m DEM from the shuttle radar topography mission (SRTM), downloadable free of charge from the GLCF website (http://glcf.umiacs.umd.edu/data/srtm). It showed that the 90 x 90 m resolution of the SRTM DEM insufficient to detect smaller depressions in the landscape while the map-derived DEM showed up even small landscape incisions made by small streams. Therefore the map-derived DEM was chosen for all surface analyses and the 3D visualisation.

The reserve boundaries were given to me by Dr. Hazel Chapman, director of the NMFP, as a set of GPS points that were collected during an ecological survey in 2001.

3.3.2.3 Field data

All field data was collected during one field season from October 2008 until February 2009. As no official documents about property ownership, property boundaries and reserve boundaries were available to me, the land use GIS layer set is mostly limited to information gathered by observation and interviews.

GPS point collection in the field was carried out with a Garmin GPSMAP 60CSx unit. Where appropriate the tracking function was used to automatically collect positional data every 30m. This information was essential when marking transhumance routes and tracing the reserve boundary.

3.3.2.3.1 Study area focus areas

The locations of the northern and eastern Ngel Nyaki boundaries were confirmed in the field by remnants of boundary demarcation beacons or, in the absence of these beacons, as herders informed me. No confirmation of the boundaries in the south and west has been attempted due to time limitations.

Property ownership was derived from interviews. Herders were walking the property boundaries with me or pointed them out where visible landmarks made this possible. Fences were delineated using the mobile GPS unit while landscape features like rivers or Eucalypt plantations demarcating property boundaries were identified and digitised from satellite imagery.

3.3.2.3.2 Farms and residential

Farm boundaries were clearly visible on the QuickBird satellite imagery (Figure 3-1) and as farms and grasslands coul not be differentiated through the spectral classification process, the farm perimeters were digitised directly from the image. The locations of herders' huts were mostly recorded while travelling extensively in the field. Huts situated too far off track to be marked by GPS were first located on the QuickBird satellite imagery and then digitised.

3.3.2.3.3 Subdivision of the study area

The whole QuickBird image was chosen as the study area (~150 km^2). After initial exploratory interpretations of the available images, the study area was divided into four primary and three secondary areas of interest (Figure 3-2). The primary areas of interest differ from the secondary areas of interest in that no field studies have been carried out in the latter. The four primary areas of interest (focus areas) consist of:

- <u>Yelwa township (including the surrounding agricultural fields)</u>

  Preliminary vegetation change images interestingly showed a net increase in the forest vegetation class in this area, which is why Yelwa was analysed separately.

- <u>Fulani properties north and east of Ngel Nyaki</u>

  As LULCC of protected areas cannot be interpreted meaningfully outside their spatial context, the trajectory of vegetation change found on the Fulani owned properties surrounding the reserve, was deemed to be important to this study. Only information about property boundaries to the east and north of the reserve was available (through interviews and observation), therefore the LULCC analysis was limited to this area.

- Ngel Nyaki (northern part)

  Splitting the area of the reserve into a northern and a southern part was deemed appropriate as the forest extent in the northern part is limited to gullies and stream banks, in contrast to the big continuous Ngel Nyaki forest, which is fully contained in the southern part of the reserve. Furthermore, the activities of the Fulani herders in the northern part (grazing and burning) were more closely observed, while scarce information about this land management is available for the southern part.

- Ngel Nyaki (southern part)

  The southern part of the reserve contains the continuous old growth forest of Ngel Nyaki. A separate analysis of this part of the reserve is appropriate, because initial screening of the data for changes in forest cover between 1988 and 2009 has revealed that the largest land cover changes have occurred in this area.

The three secondary areas of interest were classified and analysed, but no field studies have been carried out here. These areas included:

- Kurmin Danko

  Kurmin Danko is another montane forest fragment. The comparison between deforestation in this fragment compared with deforestation encountered in Ngel Nyaki was of great interest to this study

- Mambilla plateau

  Most of the land on the mambilla plateau is owned by Fulani cattle owners and managed in similar ways. Therefore a comparison between this area and the Fulani properties adjacent to the reserve, in which management was researched in detail has been carried out.

- Lowlands

  Many cattle herders seasonally move down from the plateau into the lowlands. A small part of these lowlands can be seen on the acquired QuickBird image. As land tenure for graziers differs substantially between the lowlands and the plateau an attempt has been made to assess deforestation rates and forest cover for this area as well.

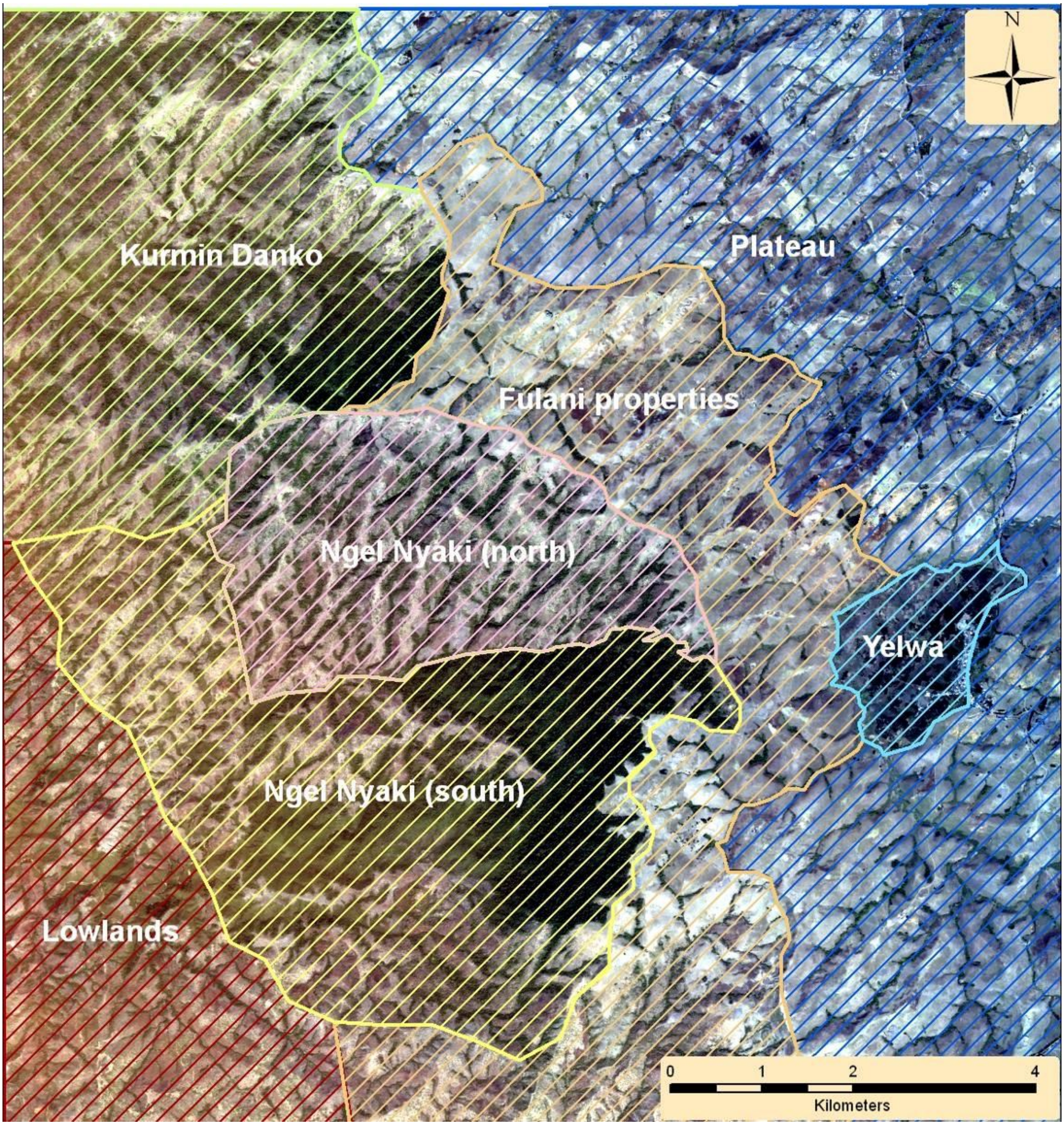


Figure 3-2: Areas of interest (sub compartments)

3.3.3 Methodology of land cover classification

The methodology used in this study mostly follows suggestions made by Aviksoo (2008), combined with the approach to ground truthing described by Heatwole (2007). The land cover classification methodology for the three satellite images was carried out in nine steps: (1) Pre-processing of the acquired satellite images, (2) Establishing forest and non-forest training areas using the pan-sharpened false colour QuickBird image, (3) Supervised classification, (4) Creating forest and non-forest masks, (5) Unsupervised classification of the masked images, (6) Identification of the training sites for supervised classification of forest and non-forest layers separately, (7) Supervised classification of the masked images, (8) Elimination of ‘salt and pepper’ noise, and (9) Analysis of the resulting maps. The details of these different steps are elaborated in the following sections.

3.3.3.1 Pre-processing of the acquired satellite images

First the Universal Transmercator Projection (UTM, 32N) was used to project the QuickBird scene which is distributed by the supplier in the geographic coordinate system (GCS-WGS1984). As the Landsat imagery was distributed already in the correct projected coordinate system, no further reprojection was needed. Once Landsat and QuickBird images were in the same projected coordinate system, the Landsat and QuickBird scenes were clipped to the extent of the study area and a perfect overlap visually confirmed (Nagendra, Pareeth & Ghate 2006). 10 GPS points taken at visible landmarks were used to verify the congruent positioning of the 3 images. Interpretation of the individual images was carried out independently, therefore no atmospheric or sensor corrections were necessary for inter-scene comparison (Aaviksoo 2008).

3.3.3.2 Establishing forest and non-forest training areas

For the establishing of training areas the common rule was followed that for each land cover class at least three training areas should be established and verified through ground-truthing where possible. The 2009 false-colour pan-sharpened QuickBird image provided enough detail to easily digitise training areas of "forest" and "non-forest" classes as well as a "burnt grassland" class (Figure 3-3).

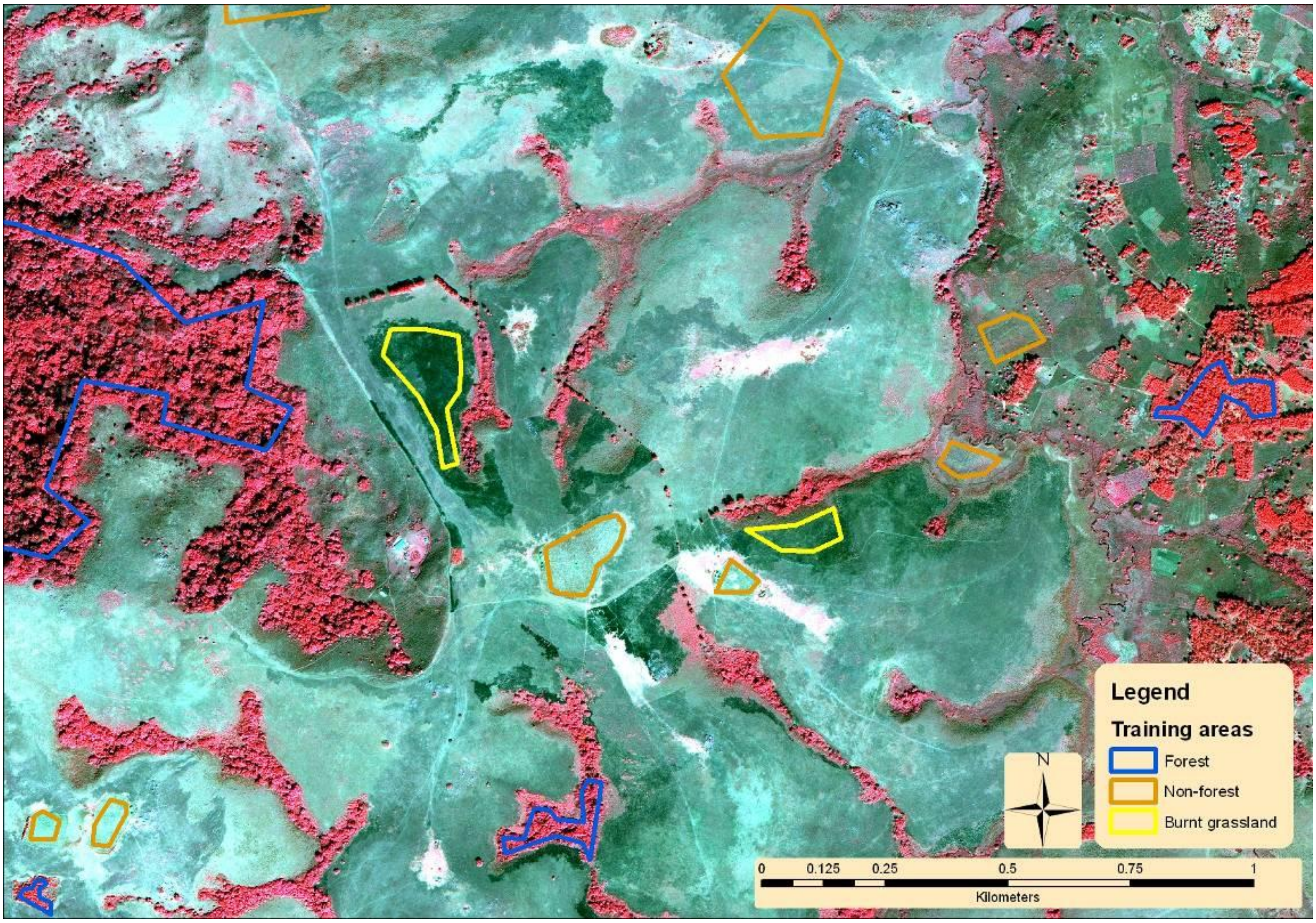


Figure 3-3: Examples of QuickBird (2009) training areas

The same method was used to determine training areas on the Landsat image from the year 2000. Landsat 7 imagery doesnot provide enough detail to be used as ground truth data. Nevertheless, by using a pan-sharpened false-colour image at least forested, non forested and burnt grassland areas were again clearly distinguishable (Figure 3-4).

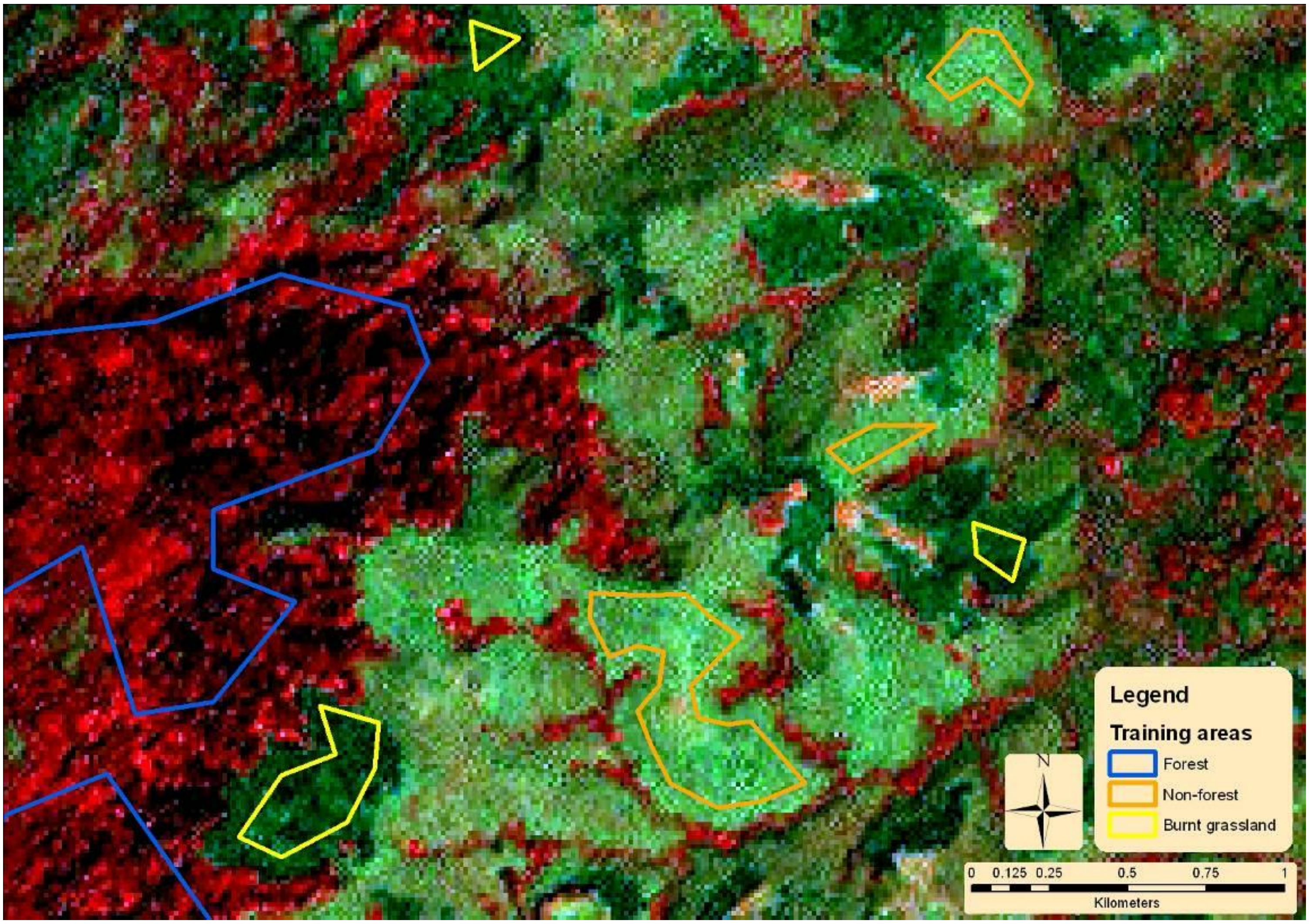


Figure 3-4: Examples of Landsat 7 (2000) training areas

For the Landsat image from the year 1988 there was no panchromatic band available and neither was ground truth data from the appropriate period. In order to define training areas for this image, interpretations of RGB and false colour images were used, as well as the knowledge of streams and forest locations in 2000. A clear visual distinction could be made between areas covered by forest, non-forested areas and burnt grassland. Analogous to the interpretation results of the 2000 and 2009 images, forest was found along stream banks and in the Ngel Nyaki old growth forest area, non-forested areas and burnt grassland were mainly found on interfluves (Figure 3-5).

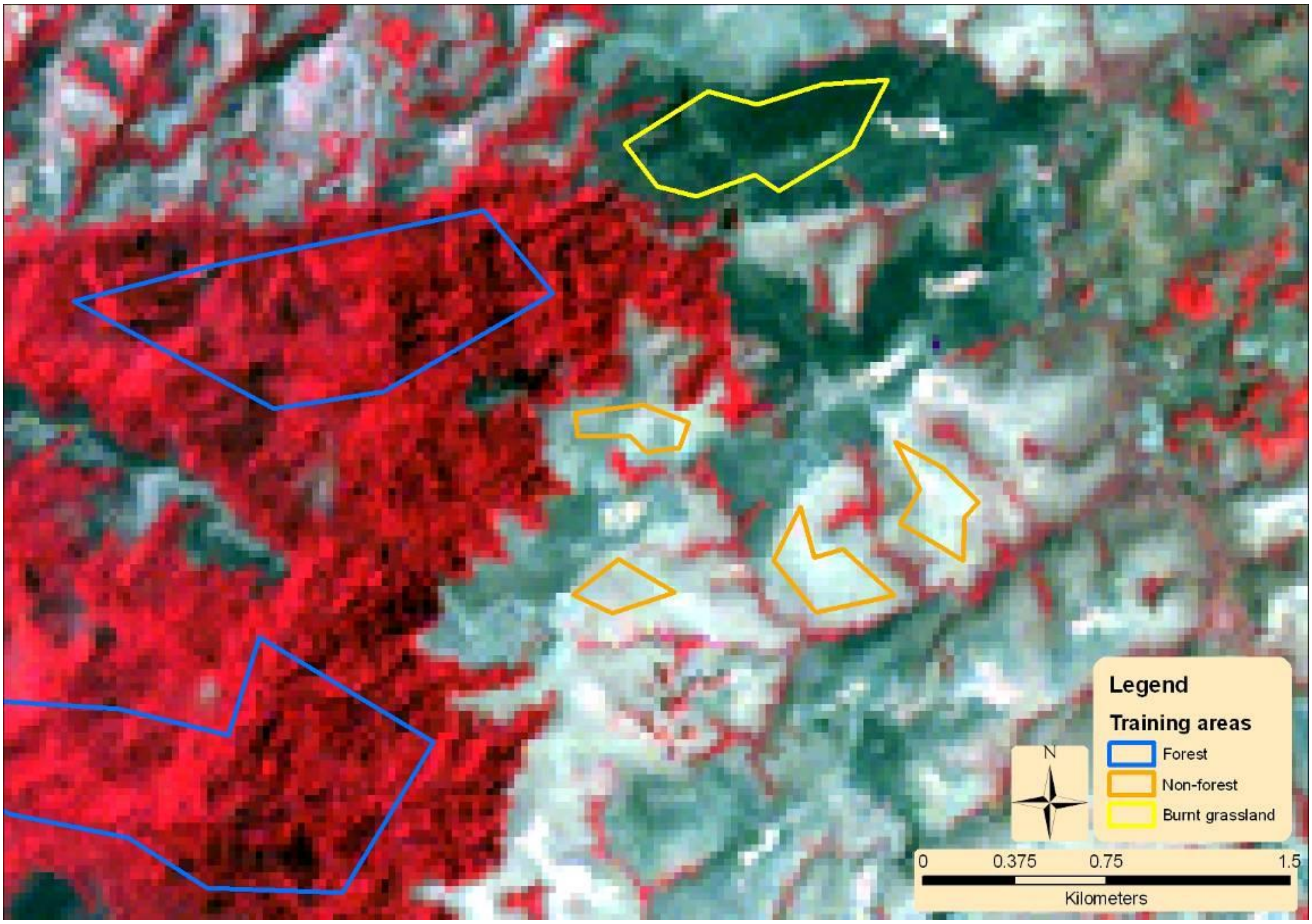


Figure 3-5: Examples of Landsat 5 (1988) training areas

Of great importance to the confidence in the selection of training areas from the 1988 image was the report of Tuley and Bawden (1966), which states that already in 1966 there were no or very few trees left on the interfluves. Chapman and Chapman (2001) also confirm this fact for the 1970s and 1980s. In fact it was stated by Chapman (2008) that during these years overall deforestation has increased, which makes using the interfluves as training areas for the “non-forest” and “burnt” classes a safe strategy.

As many studies have shown, the classification of Landsat imagery into a “forest” and a “non-forest” class can be done with high accuracy (Nagendra, Pareeth & Ghate 2006). Although no ground truth data exists for the study area for the time steps 1988 and 2000, similar good (producer’s 89.5%, κ = 84 %) accuracies can be expected here.

3.3.3.3 Supervised classification of all time steps

It is the goal of a supervised classification to assign every pixel in the study area to a known class. In the most common classification algorithm, the maximum likelihood classification (MLC), each pixel is assigned to a class according to its probability of belonging there. The ML classifier decides on this probability by comparing the multivariate statistics of the pixel with the multivariate statistics of certain pre-defined training areas of known quality (here: land cover). The dimensionality of the multivariate statistics in each case is given by the number of spectral bands used in the classification.

In the classification performed here, the first step was to create an artificial band for each time step to add an additional dimension to the analysis. The use of artificial bands has been shown to improve classification results in other studies (Hayes 2001). As the normalised differential vegetation index (NDVI) can be used to differentiate between senescent grassland, burnt grassland and photosynthetically active vegetation the NDVI was chosen as an artificial band. Due to the way it is calculated the NDVI has the additional advantage of normalising differences in reflectance that are only due to differences in illumination. In the NDVI calculation every pixel value is re-calculated by the following equation:

$$NDVI = \frac{Reflectance\ NIR - Reflectance\ RED}{Reflectance\ NIR + Reflectance\ RED}$$

Using the respective training areas for each image, all three images were then classified using the maximum likelihood classifier function in ArcGIS based on bands 1, 2, 3, 4 and the NDVI raster. Subsequently the “burnt grassland” class in all three images was reclassified to “non-forest”. Preliminary classifications found that this strategy resulted in less tree shade being misclassified as burnt grassland than an approach where the “non-forest” training class included burnt grassland.

The classification of the three images resulted in a binary maps of land cover (forest or no forest) for each time step. These different maps representing vegetation at different points in time were named T1 (from Landsat 5, 1988), T2 (from Landsat 7, 2000) and T3 (from QuickBird, 2009).

After the supervised classification the classification accuracy was determined for T3, using a confusion matrix approach (Foody 2002; Jensen 2005). No ground truth data for T1 or T2 was available on which an accuracy assessment could be based. This approach uses randomly distributed sample points to compare the predicted class with the real class at each sample point as assessed by visual interpretation (Figure 3-6). As a result the overall classification accuracy can be reported as well as the accuracy adjusted for correct class assignment by chance (κ-value). Additionally the user's and producer's accuracy can be calculated, which give an indication of classification accuracy within classes and take into account omission and commission errors (Foody 2002; Jensen 2005; Aaviksoo 2008).

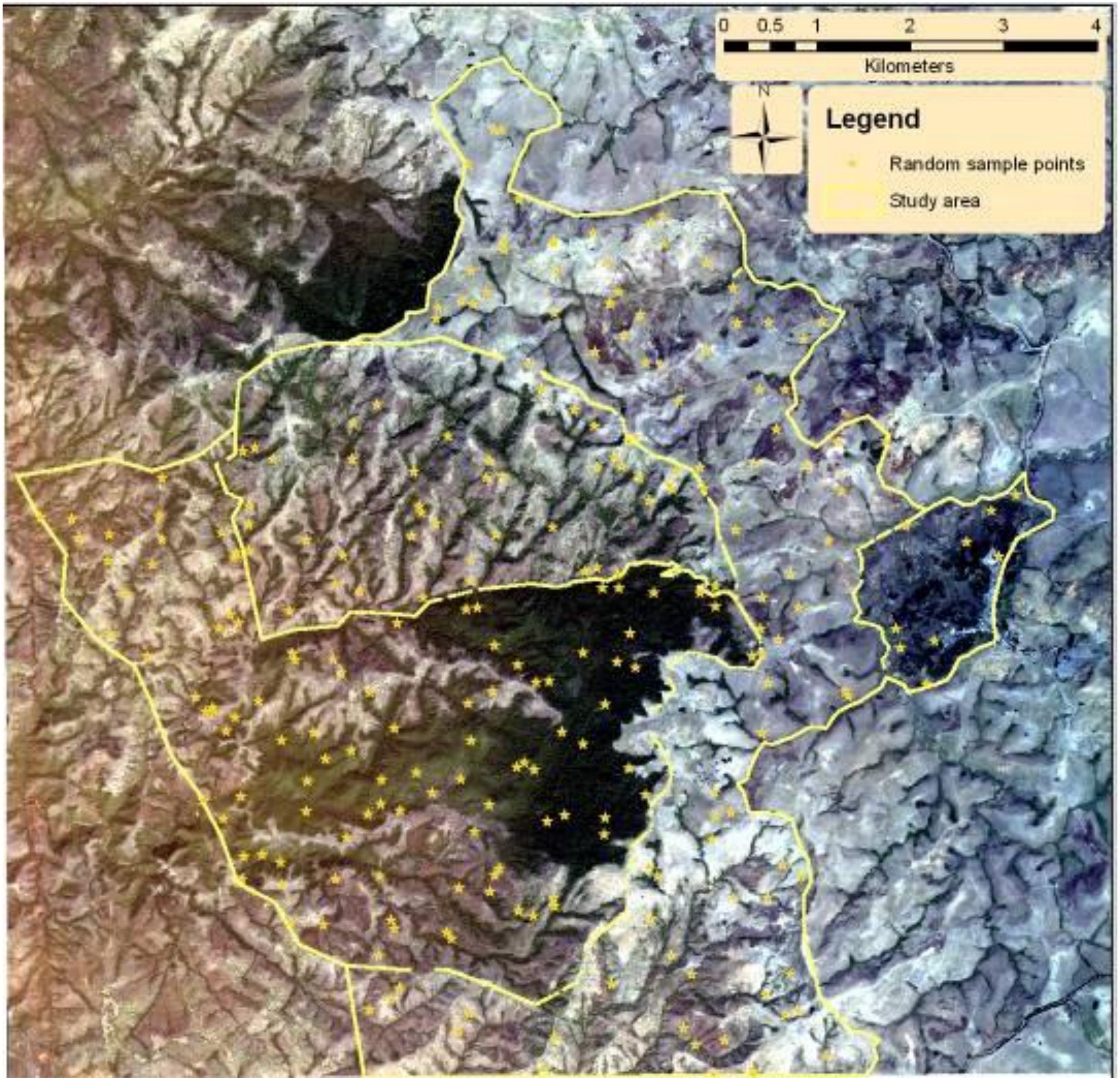


Figure 3-6: Classification accuracy assessment using simple random sampling

In the classification performed here an overall classification accuracy of 92.8% was achieved. Due to the same amount of omission and commission errors, user's and producer's accuracies were the same: (90.3% (forest), 94.3% (non-forest). Cohen's kappa coefficient was 0.846.

Table 3-2: Error matrix to assess Forest/Non-forest classification accuracy

		Actual Class		
		Forest	Grassland	Row sum
Classification results	forest	84	9	93
	grassland	9	148	157
	Column Sum	93	157	250

Overall classification accuracy:	92.8%
Producer's accuracy:	90.3% (forest), 94.3% (non-forest)
User's accuracy	90.3% (forest), 94.3% (non-forest)
κ-value:	0.846

3.3.3.4 Creating forest and non-forest masks

Due to unavailability of suitable ground-truth data for the time steps 1988 and 2000 it was only possible to classify the 2009 time step further.

As the classification was judged to be very accurate the two classes (forest and non-forest) were extracted and used to mask forested and non-forested areas on the QuickBird image. The masks were then used to extract forest and non-forest pixels from bands 1, 2, 3 and 4 of the QuickBird imagery and from the NDVI raster. The rasters thus extracted were then stacked as a composite image of 5 bands.

3.3.3.5 Identification of training sites for supervised classification of non-forest areas

The additional step of further classifying the non-forest areas of the 2009 image was carried out in order to create a more detailed land cover map for this year following objective 1 of section 3.2.

Many features of the landscape, like recently burnt patches of grassland, older burnt patches, kikuyu grass, tussock grassland, farms, bare soil, rocks and iron roofs were able to be identified using the pan sharpened false-colour QuickBird image. A subset of these landscape features (3+ per land cover class) were used as training areas for a supervised classification.

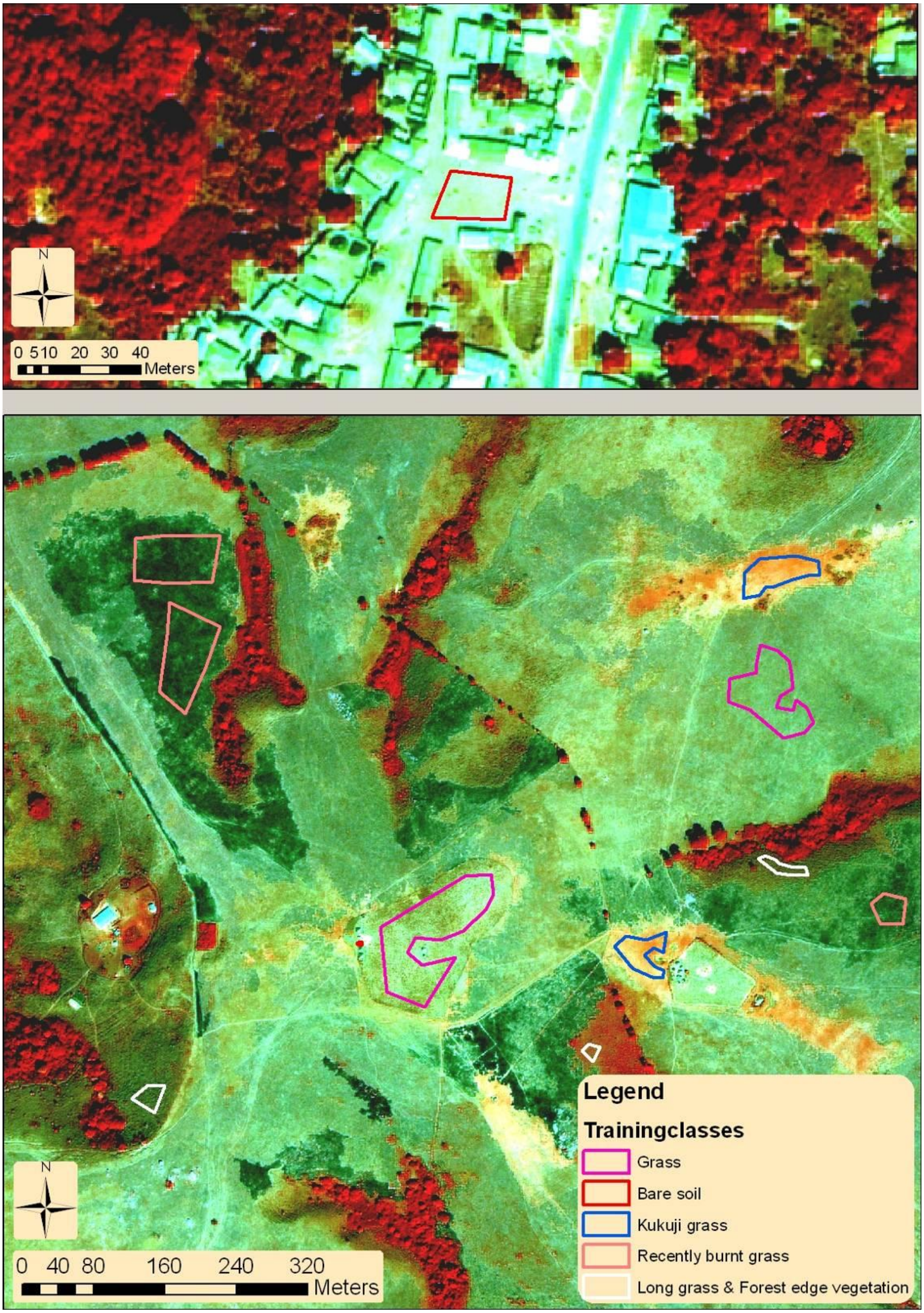


Figure 3-7: Training areas for detailed land cover classification

3.3.3.6 Supervised classification of non-forest areas

A supervised classification of the non-forested areas was carried out analogous to that described in section 3.3.3.3 using the previously depicted training areas. An error matrix has been created to assess the accuracy of the resulting classification analogous to section 3.3.3.3.

This classification is much more detailed than the binary output of the forest/non-forest classification and hence heterogeneous areas show a variety of different pixels. It is impossible to ground truth every pixel exactly by using QuickBird imagery or any other means due to spectral blurring of neighbouring pixels. Therefore the widely accepted method of defining the class of a pixel by the class of the majority of neighbouring pixels (3x3 pixel frame centred on the selected pixel) was used (Foody 2002).

3.3.3.7 Elimination of 'salt and pepper' noise

The forest and non-forest areas thus classified were merged into a single map. Due to the frequent occurrence of 'salt-and pepper noise' (individual pixels with a differing LC category than in neighbouring pixels) in classification results (Aaviksoo 2008) a 3x3 pixel majority filter (median) was applied to produce the final land cover map.

3.3.3.8 Analysis of results

Due to the different time scales between images (13 years and 8 years) and the widely differing spatial extents of subdivisions, annual deforestation rates and relative forest cover of the different subdivisions are compared.

In the following analysis 'deforestation' is defined as pixels that were classified as 'forest' in the previous time step and as 'non-forest' in the next time step. Conversely, 'regeneration' is defined as pixels that were classified as 'non-forest' in the previous time step and as 'forest' in the next. The calculation of average annual deforestation rates in percent are calculated as described by Puyravaud (2003) by the formula:

$$P = \frac{1}{\Delta t} \frac{A_2 - A_1}{A_1}$$

,where Δt is the time between observations, A_1 is the forested area at time step 1, A_2 is the forested area at time step 2 and P is the rate of deforestation or forest expansion in percent.

In another analytic step the total area disturbed by deforestation is examined separately from regeneration. One of the advantages of analysing deforestation and regeneration separately is that the total area disturbed by landscape conversion can be assessed. Just analysing net deforestation masks this important fact which may be of great ecological significance. This is especially true if it is considered that after destruction of a forest habitat (deforestation) it may take a long time before this habitat is restored and solely the expansion of pioneer trees into previously deforested areas often does not provide the same conditions for ecosystem functioning although on a thematic land cover map, the area is classed as forested.

3.3.4 Methodology for the detection and mapping of land cover change

In this study, three different satellites with different sensor (and other) specifications were used to provide vegetation data at three different points in time. Due to these differences in hardware and potential differences in environmental characteristics, the three images cannot be compared directly (Jensen 2005). Hence, many approaches to change detection require sensor, atmospheric and radiometric corrections of the imagery (among others) (Soudani *et al*. 2006).

The common method of NDVI differencing[7] is also not appropriate in this case as the QuickBird derived NDVIs are considerably offset compared to Landsat derived NDVIs (Soudani *et al.* 2006) and not all acquisition differences can be accounted for by mathematical transformations (van Leeuwen *et al.* 2006).

However, there are other approaches, among them post-classification comparison, which do not require these corrections. The post-classification comparison of change uses individually classified images as input data. This ensures that environment and sensor specific variations in the data are not translated into 'change' by the change detection algorithm.

For land cover change detection the classified Quickbird image T3 was resampled to 28.5 x 28.5 m resolution to match the resolution of the Landsat imagery. The "majority" algorithm was used on the image because this resembles the method by which the cover class of the lower resolution images is determined: The value that a particular pixel has in each spectral band, is determined by the resolution of the sensor and the reflectance properties of a corresponding surface at ground level. The size over which the sensor integrates depends on its resolution. In this example the reflectances of multiple objects in a 28.5 x 28.5 m patch are integrated and result in a certain pixel value. The more area an object of particular reflectance properties assumes within this patch the more will this object's reflective properties contribute to the pixel value. The maximum likelihood classifier will classify pixels that have a high contribution of object A in one class and objects that have a high contribution of object B in a different class. This process is very similar in nature to the 'majority' resampling method (Petit 2001).

The comparison between two time steps is carried out by image differentiation and results in a transition matrix which consists of the 'from class - to class'-information of each individual pixel (Jensen 2005).

[7]NDVI differencing is a method whereby the NDVI value of each pixel of an image of one time step is subtracted from the NDVI value of the corresponding pixel in a later time step. Hence the difference in NDVI can be calculated. The results of this procedure can be interpreted as changes in photosynthetic activity.

After successful classification of the three images, T1 (Landsat 5, 1988), T2 (Landsat 7, 2000) and T3 (QuickBird, 2009) three differential images were created: T2-T1 (representing change between 1988 and 2000), T3-T2 (representing change between 2000 and 2009) and T3-T1 (representing change between 1988 and 2009).

Masks representing the four subdivisions of the study area (Yelwa, Fulani properties, Ngel Nyaki reserve (north), Ngel Nyaki reserve (south)) were used to evaluate changes in each area separately.

3.4 Results

3.4.1 Land cover classification

3.4.1.1 Detailed land cover classification 2009

The detailed land cover map derived from QuickBird satellite imagery shows a thematic representation of the current landscape (Figure 3-8
Figure 3-8). Apart from showing their spatial distribution, the classification also provides information about the spatial extent of the different classes.

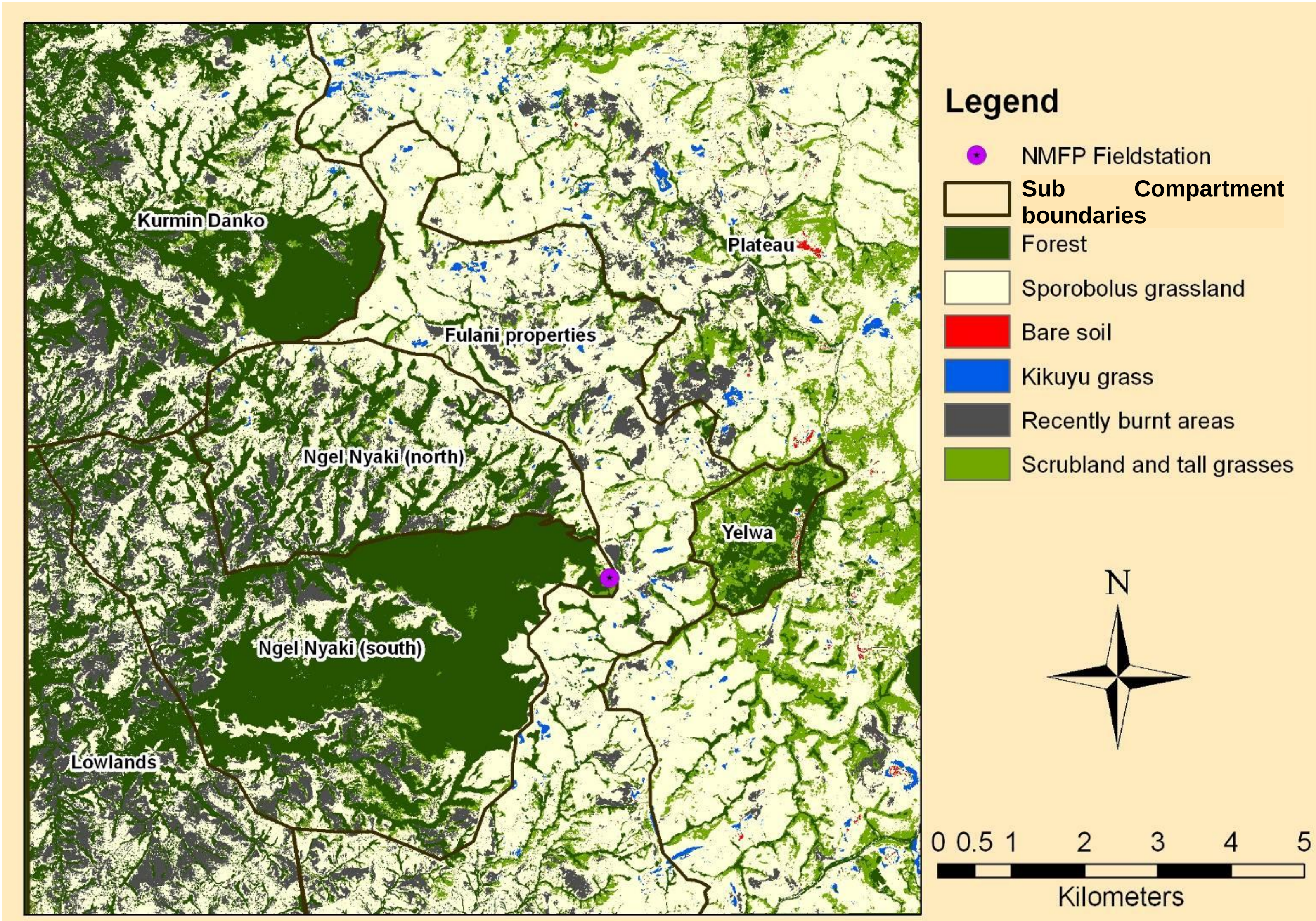


Figure 3-8: Thematic map of land cover (2009)

Many landscape features, like forests, Sporobolus grassland, farmland, open savannah, recently burnt patches of grassland, older burnt patches, bare soil, kikuyu grass, rocks, thatched and iron roofs, rivers and even cattle herds were visible on the pan-sharpened false-colour QuickBird image. Some of these features however were only able to be visually discerned due to their texture or the spatial context in which they appear. This information is readily available to a skilled human interpreter but not to the computer on which the pixel based classification depends. When classifying the image based on differences in spectral reflectance only the following six classes were discernable: forests, grassland, bare soil, kikuyu grass, recently burnt areas and scrubland / tall grasses.

The overall accuracy of the classification was estimated to be 87.9% with a kappa coefficient of 0.817 (Table 3-3). An overall classification accuracy of >85% is usually taken as the boundary for good classification accuracy while the accuracies in different classes should be approximately even (Foody 2002).

Table 3-3: Accuracy assessment of the detailed land cover classification

		True Land cover					
		Grassland	Forest	Scrubland	Burnt	Row sums	User's Accuracy
Classification results	Grassland	206	3	23	8	240	85.8%
	Forest	6	130	2	0	138	94.2%
	Scrubland	1	2	42	0	45	93.3%
	Burnt	13	1	0	50	64	78.1%
	Column sums	226	136	67	58	487	
	Producer's accuracy	91.2%	95.6%	62.7%	86.2%		
Overall Accuracy		87.9%					
Kappa Coefficient		0.817					

The User’s accuracy for the burnt class and the producer’s accuracy of scrubland are relatively low with 78.1% and 62.7% respectively. The classification often confused burnt grass and grassland sites, which is not surprising given that the boundaries between burnt and unburnt grassland are necessarily blurred. The strong tendency of the classification of misclassifying scrubland as grassland is explained by the grass component in the scrubland class, which was not very well discernable from *Sporobolus* grassland using only the spectral bands offered by QuickBird imagery. The fact that grassland was not often misclassified as scrubland can probably be ascribed to the differences in proportional land cover between the two classes (see Table 3-4). Kikuyu grass and bare soil classes have been omitted from the classification accuracy assessment as their relative contributions to the total extent of land cover, and hence their contributions to the total error of the thematic map for the study area is negligible (see Table 3-4). In summary, the classification is sufficiently accurate, the overall accuracy and the kappa coefficient are within the boundary of what is classed good classification accuracy (Foody 2002), nevertheless, due to the nature of the smooth transitions of burnt and unburnt grass as well as the partial grass cover included in the “scrubland” class these classifications were associated with larger errors.

The study area’s total extent is 150 km^2 and within this area forests cover ~27%, Sporobolus grassland ~52%, scrubland and tall grasses ~10%, while Kikuyu grass and bare soil only cover ~0.8% and 0.2% respectively. Another land cover class, consisting of recently burnt areas is covering ~11% of the study area and provides a first impression of current land use patterns / land management regimes in the area which will be examined in chapter 5.4 in more detail (Table 3-4).

Table 3-4: Extents of different land cover classes in the study area

<table>
<tr><th>Visually discernable classes</th><th>Spectrally discernable classes</th><th>Land cover [ha]</th><th>Land cover [%]</th></tr>
<tr><td>Forest</td><td>Forest</td><td>3998.8</td><td>26.6%</td></tr>
<tr><td>Grassland</td><td rowspan="6">Grassland</td><td rowspan="6">7753.7</td><td rowspan="6">51.7%</td></tr>
<tr><td>Farmland</td></tr>
<tr><td>Open Savannah</td></tr>
<tr><td>Older burns</td></tr>
<tr><td>Rocks</td></tr>
<tr><td>Roofs</td></tr>
<tr><td>Kikuyu grass</td><td>Kikuyu grass</td><td>123.9</td><td>0.8%</td></tr>
<tr><td>Tall grasses</td><td rowspan="2">Scrubland and tall grasses</td><td rowspan="2">1474.0</td><td rowspan="2">9.8%</td></tr>
<tr><td>Shrubs</td></tr>
<tr><td>Road</td><td rowspan="2">Recently burnt</td><td rowspan="2">1636.4</td><td rowspan="2">10.9%</td></tr>
<tr><td>Recent burns</td></tr>
<tr><td>Bare soil</td><td>Bare soil</td><td>23.9</td><td>0.2%</td></tr>
<tr><td>Cattle herds</td><td></td><td></td><td></td></tr>
<tr><td>Rivers</td><td></td><td></td><td></td></tr>
</table>

Although QuickBird imagery was used to ground-truth the classification, the limitations of this approach clearly showed during the classification process.

Nevertheless, even considering these limitations the extents of land cover types could still be assessed (Table 3-5).

Table 3-5: Detailed breakdown of land cover present in the different subdivisions of the study area

Area	Forest cover [ha]	Forest cover [%]	Sporobolus grassland [ha]	Sporobolus grassland [%]	Bare soil [ha]	Bare soil [%]	Kikuyu grass [ha]	Kikuyu grass [%]	Recently burnt areas [ha]	Recently burnt areas [%]	Scrubland & tall grasses [ha]	Scrubland & tall grasses [%]
Plateau	413.8	7.9%	3569.9	68.0%	20.9	0.4%	81.6	1.6%	267.7	5.1%	881.1	16.8%
Kurmin Danko	1025.7	45.6%	809.4	36.0%	0.0	0.0%	6.7	0.3%	290.3	12.9%	116.7	5.2%
Lowlands	436.8	34.0%	450.3	35.0%	0.0	0.0%	0.2	0.0%	374.7	29.2%	21.8	1.7%
Fulani Properties	234.2	9.4%	1782.8	71.5%	1.3	0.1%	31.6	1.3%	240.5	9.7%	184.9	7.4%
Yelwa	105.9	40.6%	44.3	17.0%	1.6	0.6%	0.5	0.2%	1.9	0.7%	106.8	40.9%
Ngel Nyaki (south)	1385.0	60.0%	539.2	23.3%	0.0	0.0%	0.5	0.0%	295.4	12.8%	90.4	3.9%
Ngel Nyaki (north)	397.0	33.2%	557.9	46.7%	0.1	0.0%	2.8	0.2%	165.8	13.9%	72.4	6.1%
Total	**3998.35**		**7753.8**		**23.9**		**123.9**		**1636.2**		**1474.0**	

When comparing the characteristics of different subdivision areas with each other, it becomes apparent that the Fulani properties adjacent to the reserve and the plateau area display very similar land cover characteristics (Figure 3-8). They both have very little forest cover, very extensive grassland cover and both have similar extents of Kikuyu grass cover. On the other hand, the plateau area shows larger extents of bare soil than the Fulani properties adjacent to the reserve, in fact larger extents than any other subdivision except Yelwa Township. Another difference is that in the plateau area there are more scrubland and tall grasses present and less recently burnt areas than in the properties next to the reserve.

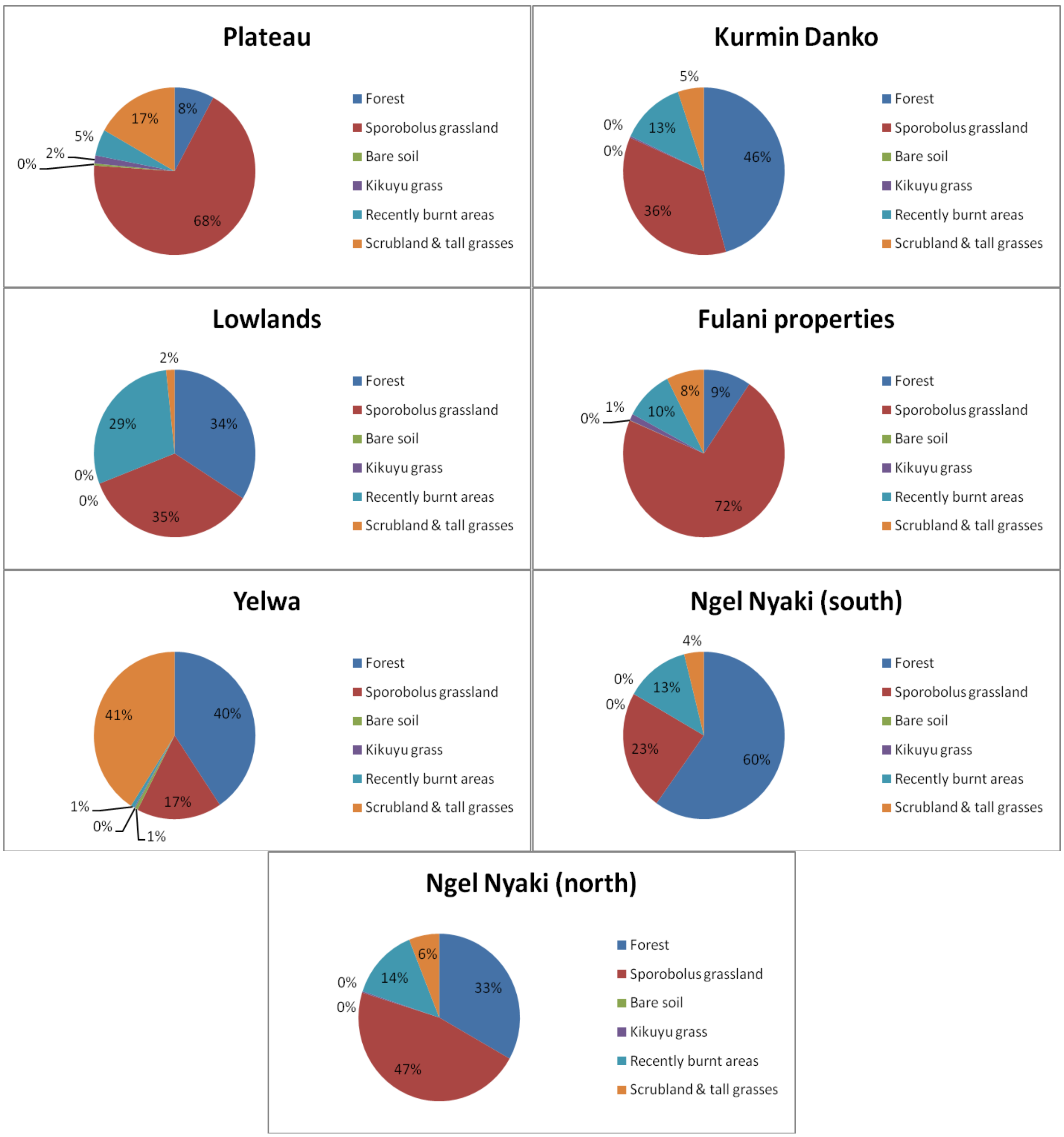


Figure 3-9: Land cover characteristics of different landscape subsets

Kurmin Danko and southern Ngel Nyaki are both forest dominated subdivisions with the same extents of recent burns and comparable sizes of the scrubland and tall grass land cover class. Kurmin Danko however has less forest and more grassland than Ngel Nyaki (south).

The lowlands are characterised by comparatively very little scrubland & tall grass vegetation cover. At the same time the percentage of recently burnt landscape is extraordinarily high compared to the other subdivisions. The extent of forest is similar to that of Ngel Nyaki (north).

Ngel Nyaki (north) shows similar extents of recently burnt areas and scrubland and tall grass vegetation as Kurmin Danko, Ngel Nyaki (south) and Fulani properties adjacent to the reserve. Its forest extent is larger than the forest extent on Fulani properties, but smaller than the extent in Ngel Nyaki (south) or Kurmin Danko. Conversely, its grassland extent is smaller than the grassland extent on Fulani properties, but larger than the extent in Ngel Nyaki (south) or Kurmin Danko. When compared with the lowlands Ngel Nyaki (north) displays considerably less recently burnt areas but slightly more scrubland, while presenting considerably larger areas of grassland. Forest extents are almost equal in these two areas.

Yelwa township contains the highest amount of bare soil and the largest area of scrubland and tall grasses among all subdivisions. Also its other cover classes are prominent: It has the third largest forest cover extent after Ngel Nyaki (south) and Kurmin Danko while the recently burnt cover category is conspicuously low.

3.4.1.2 Land cover classification 1988 for LULCC assessment

The land-cover classification of 1988 with the help of Landsat TM imagery revealed that at this time 4486 ha of the study area was forested and 10,558 ha non-forested (Table 3-6) which equates to an overall forest cover of 29.2% and a corresponding non-forest cover of 70.2%.

Table 3-6: Land cover in 1988 (T1)

Area	Total area [ha]	Forest cover [ha]	Forest cover [%]	Non-forest cover [ha]	Non-forest cover [%]
Plateau	5251	451	9%	4800	91%
Kurmin Danko	2249	1171	52%	1078	48%
Lowlands	1284	435	34%	849	66%
Fulani Properties	2493	261	10%	2232	90%
Yelwa	261	85	33%	176	67%
Ngel Nyaki (south)	2310	1590	69%	720	31%
Ngel Nyaki (north)	1196	494	41%	702	59%
Total	15044	4486		10558	

Among the subdivisions forest cover varies substantially. The plateau and the Fulani properties adjacent to the reserve show the least forest cover (9% and 10%). Yelwa township has a high forest cover of 33%, which is similar to forest cover in the lowlands (34%), while northern Ngel Nyaki yields low forest cover (41%), given its reserve status. The Kurmin Danko area and the southern part of Ngel Nyaki display the highest forest cover (52% and 69%). Over 60% of total forest cover in the study area is located in these two fragments alone and they not only have the highest relative forest cover, but also by far the highest absolute forest cover among all subdivisions.

3.4.1.3 Land cover classification 2000 for LULCC assessment

The classified Landsat ETM+ image from the year 2000 showed that a total of 4475 ha (29.7%) were forested, while 10596 ha (70.3%) were not forested (Table 3-7).

Table 3-7: Land cover in 2000 (T2)

Area	Total area [ha]	Forest cover [ha]	Forest cover [%]	Non-forest cover [ha]	Non-forest cover [%]
Plateau	5251	423	8%	4828	92%
Kurmin Danko	2249	1310	58%	939	42%
Lowlands	1284	452	35%	832	65%
Fulani Properties	2493	296	12%	2197	88%
Yelwa	261	78	30%	183	70%
Ngel Nyaki (south)	2310	1435	62%	875	38%
Ngel Nyaki (north)	1196	480	40%	716	60%
Total	15044	4475		10569	

In the year 2000 the plateau area and the Fulani properties adjacent to the reserve again had the lowest forest cover (8% and 12%). Yelwa township had the next lowest (30%), followed by the lowlands (35%) and northern Ngel Nyaki (40%). Kurmin Danko and southern Ngel Nyaki again displayed the highest forest cover among all subdivisions.

3.4.1.4 Land cover classification 2009 for LULCC assessment

The QuickBird image from 2009 was resampled to match the resolution of the older Landsat images and classified for LULCC assessment. The classification result suggests that in 2009 only 3784 ha (25%) remained forested, while 11260 ha (75%) of the study area were not forested.

Table 3-8: Land cover distribution in 2009 (T3)

Area	Total area [ha]	Forest cover [ha]	Forest cover [%]	Non-forest cover [ha]	Non-forest cover [%]
Plateau	5251	321	6%	4930	94%
Kurmin Danko	2249	1007	45%	1242	55%
Lowlands	1284	404	31%	880	69%
Fulani Properties	2493	181	7%	2312	93%
Yelwa	261	103	39%	158	61%
Ngel Nyaki (south)	2310	1384	60%	926	40%
Ngel Nyaki (north)	1196	384	32%	812	68%
Total	15044	3784		11260	

A breakdown of the study area into individual subdivisions shows that the plateau and the Fulani properties adjacent to the reserve still have the least forest cover of all subdivisions. Then, however, come the lowlands with 31%, closely followed by northern Ngel Nyaki with 32% forest cover. Yelwa Township now has a higher forest cover (39%) than the previous two areas and Kurmin Danko and southern Ngel Nyaki still have the highest forest cover (45% and 60%).

As can be deduced from these tables, significant changes in forest cover have occurred during the last 21 years. The quantities and locations of these changes have been further analysed in the next chapter.

3.4.2 Land cover change analysis

3.4.2.1 Net forest cover change between 1988 and 2009

Over the whole time period ~33 ha of forest cover was lost annually to expanding grassland (Table 3-9). This equates to an annual deforestation rate of 0.8 %. However, deforestation rates have not been equal during the two time periods under observation: between 1988 and 2000 only 0.8 ha of forest were lost annually (~0.02%). In the time period between 2000 and 2009 net deforestation rates rose 1000% to 86.3 ha per year. This equates to an annual deforestation rate as high as ~1.9 % during that time period.

Table 3-9: Net forest cover change in the study area

Time period	1988-2000		2000-2009		1988-2009	
Area	Annual forest cover change					
	[ha/yr]	[%/yr]	[ha/yr]	[%/yr]	[ha/yr]	[%/yr]
Plateau	-2.1	-0.5%	-12.8	-3.0%	-6.2	-1.4%
Kurmin Danko	10.7	0.9%	-38.0	-2.9%	-7.8	-0.7%
Lowlands	1.4	0.3%	-6.0	-1.3%	-1.4	-0.3%
Fulani Properties	2.7	1.1%	-14.3	-4.8%	-3.8	-1.4%
Yelwa	-0.6	-0.7%	3.1	4.0%	0.8	1.0%
Ngel Nyaki (south)	-11.9	-0.8%	-6.5	-0.5%	-9.8	-0.6%
Ngel Nyaki (north)	-1.1	-0.2%	-11.9	-2.5%	-5.2	-1.1%
Total	**-0.8**	**-0.02%**	**-86.3**	**-1.9%**	**-33.4**	**-0.8%**

When the different subdivisions of the study area are examined separately it becomes apparent that rates of deforestation differ widely spatially as well as temporally. A spatial analysis of cover change reveals that over the whole time period the plateau area and Fulani properties had the highest annual deforestation rate (1.4% and 1.4%), closely followed by northern Ngel Nyaki (1.1%). Ngel Nyaki (south) and Kurmin Danko had similar deforestation rates (0.6% and 0.7%) while exhibiting the highest absolute loss of forest cover (9.8 ha and 7.8 ha). The lowlands face comparatively little deforestation in relative (0.3%) and absolute terms (1.4 ha). Yelwa township, as previously mentioned is the only subdivision displaying a slight net increase in forest cover (0.8 ha, 1.0%)

Separating these results out into two time periods, further differences can be observed: In the time period 1988-2000 slight forest expansion can be witnessed in the Kurmin Danko area (0.9%) as well as in the lowlands (0.3%) and on the

Fulani properties (1.1%). On the other hand forest loss is noticeable on the plateau (0.5%), in Yelwa Township (0.7%), in northern Ngel Nyaki (0.2%) but most prominently in southern Ngel Nyaki (0.8%). Ngel Nyaki (south) also had the largest absolute loss of forest cover among all subdivisions (11.9 ha). It even exceeds the extent of regeneration seen in the Kurmin Danko area (10.7ha) in absolute terms.

During the time period 2000-2009 all subdivisions except Yelwa lost forest cover. The biggest relative loss is observed on the Fulani properties surrounding the reserve (4.8%), followed by the plateau (3.0%), Kurmin Danko (2.9%), northern Ngel Nyaki (2.5%), the lowlands (1.3%) and finally southern Ngel Nyaki (0.5%). In absolute terms Kurmin Danko lost by far the most forest cover (38.0 ha). The plateau, Fulani properties and Ngel Nyaki north lost similar amounts of forest cover (12.8 ha, 14.3 ha and 11.9 ha) while southern Ngel Nyaki and the lowlands also lost similar amounts (6.5 ha and 6.0 ha). Only Yelwa displays an increase in forest cover (3.1 ha, 4.0%).

3.4.2.2 Forest regeneration and forest loss between 1988 and 2009

Since 1988 the remaining forests in the study area have shrunk considerably. This however does not mean that no regeneration has occurred in that period. Presented here are the changes in forest cover (deforestation and regeneration) that have taken place between 1988 and 2009. From a first visual interpretation it becomes apparent that the dominant land cover change in the study area is deforestation (Figure 3-10).

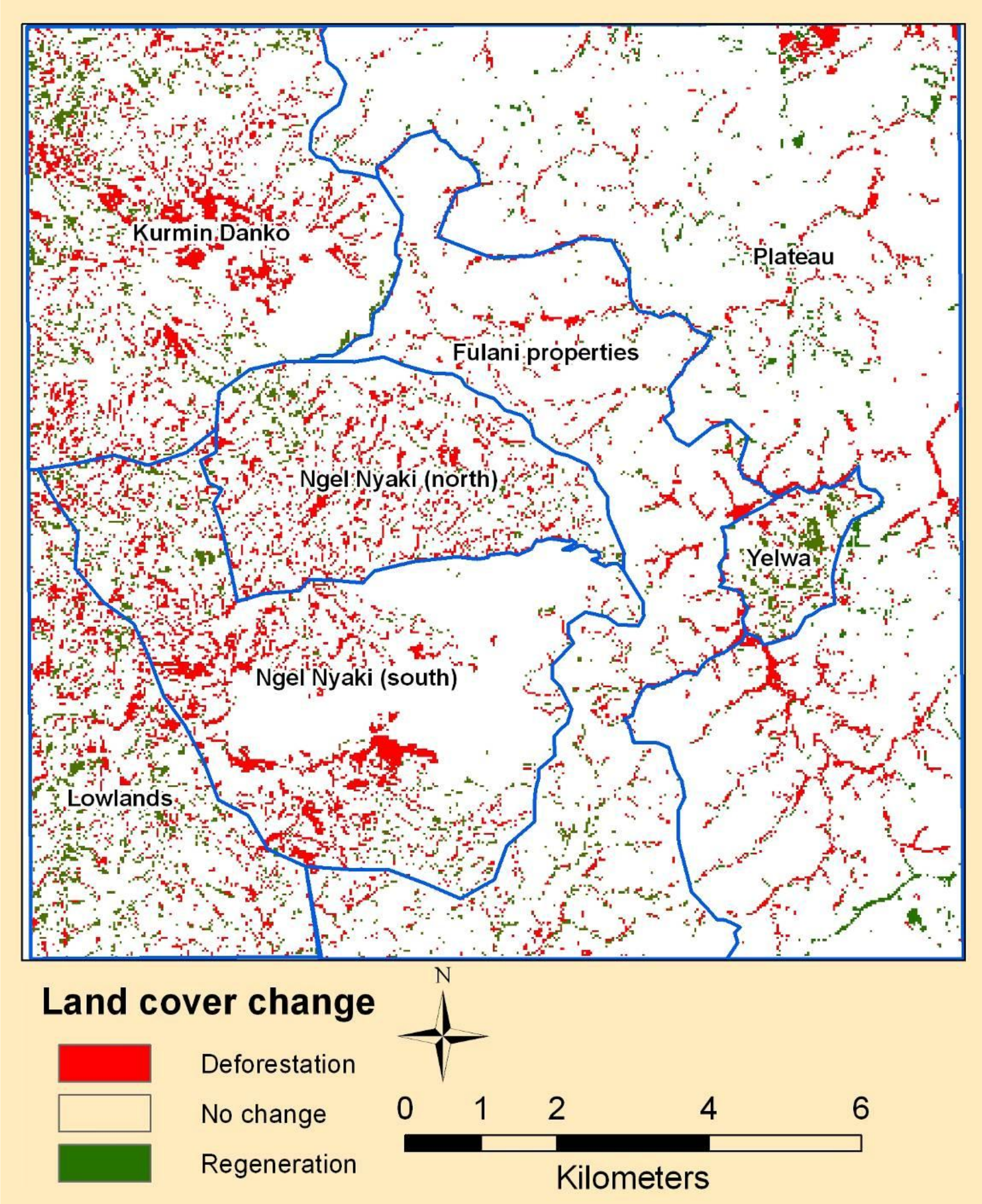


Figure 3-10: Deforestation and forest regeneration between 1988 and 2009

To analyse the occurring changes in more depth, the different types of change (deforestation or regeneration) are compiled and presented by subdivision. When looking at ecosystem destruction and analysing the different areas from this perspective the most striking difference is observed in the lowlands (Table 3-10). Although net annual deforestation there is relatively low, this analysis reveals that gross annual deforestation is actually similar to that of Ngel Nyaki (north). The smaller net deforestation described earlier can hence be attributed to a regeneration rate in the lowlands that is 270% as high as in Ngel Nyaki (north). Similarly it can be established that although Ngel Nyaki (south) and Kurmin Danko have similar net deforestation rates Kurmin Danko experiences 140% more deforestation which is masked by a higher rate of regeneration.

Table 3-10: Deforestation and regeneration between 1988 and 2009 by subdivision

Subdivision	Area [ha]	Type of change	Annual conversion		Net annual conversion
			[ha]	[%]	[%]
Plateau	5251	Deforestation	-12.08	-2.68%	-1.37%
		Regeneration	5.90	1.31%	
Kurmin Danko	2249	Deforestation	-13.43	-1.15%	-0.67%
		Regeneration	5.61	0.48%	
Lowlands	1284	Deforestation	-6.54	-1.50%	-0.33%
		Regeneration	5.10	1.17%	
Fulani properties	2493	Deforestation	-6.63	-2.54%	-1.44%
		Regeneration	2.87	1.10%	
Yelwa	261	Deforestation	-1.18	-1.38%	0.96%
		Regeneration	2.00	2.34%	
Ngel Nyaki (south)	2310	Deforestation	-12.97	-0.82%	-0.62%
		Regeneration	3.14	0.20%	
Ngel Nyaki (north)	1196	Deforestation	-7.35	-1.49%	-1.06%
		Regeneration	2.14	0.43%	

3.4.2.3 Forest regeneration and forest loss between 1988 and 2000

When visually analysing the land cover changes between 1988 and 2000 the most prominent changes are seen in the Kurmin Danko area, which shows large areas of regeneration, and Ngel Nyaki (south) which shows large areas of deforestation (Figure 3-11). All other subdivisions show deforestation and regeneration without a clear predominance of either conversion type.

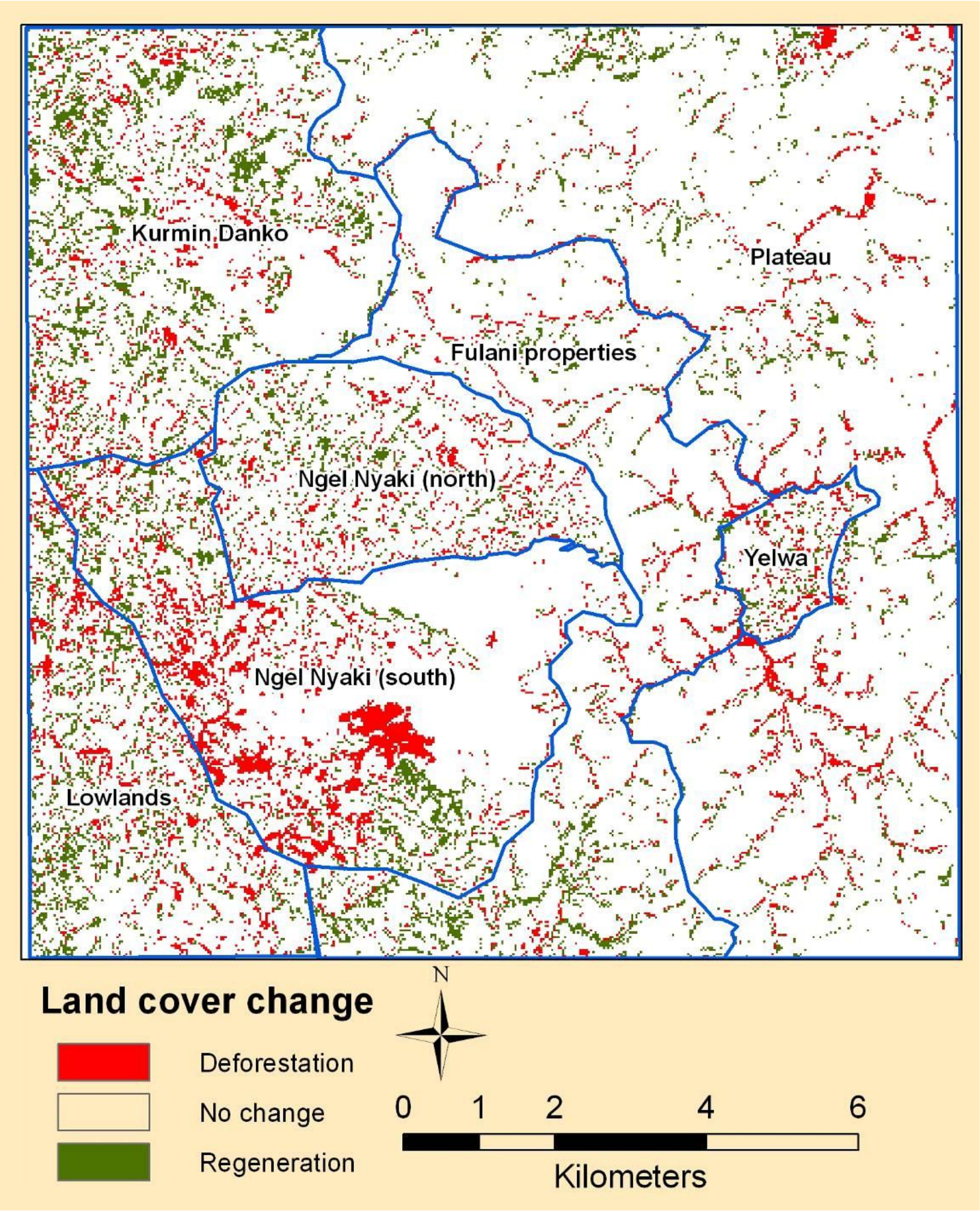


Figure 3-11: Deforestation and forest regeneration between 1988 and 2000

It is therefore advisable to once again consult a table which lists deforestation and regeneration according to subdivision for the period between 1988 and 2000. It is an interesting feature of this time period that although net deforestation and net regeneration values are relatively low, this is not due to a lack of deforestation but to relatively high regeneration rates for these years.

It is notable that the two areas with the highest rates of deforestation (plateau and Fulani properties) display relatively low net deforestation (plateau) or even regeneration (Fulani properties). Ngel Nyaki (south) on the other hand experienced the highest net deforestation rate in this time period although its gross deforestation rate is lower than that of Ngel Nyaki (north). Ngel Nyaki (north) displays a regeneration rate of 192% of Ngel Nyaki (south), which results in very little net deforestation in this area.

Table 3-11: Deforestation and Regeneration between 1988 and 2000 by subdivision

Subdivision	Area [ha]	Type of change	Annual conversion		Net annual conversion
			[ha]	[%]	[%]
Plateau	5251	Deforestation	-16.42	-3.64%	-0.46%
		Regeneration	14.32	3.18%	
Kurmin Danko	2249	Deforestation	-11.29	-0.96%	0.92%
		Regeneration	22.03	1.88%	
Lowlands	1284	Deforestation	-10.23	-2.35%	0.31%
		Regeneration	11.58	2.66%	
Fulani properties	2493	Deforestation	-8.98	-3.44%	1.05%
		Regeneration	11.72	4.50%	
Yelwa	261	Deforestation	-2.43	-2.85%	-0.68%
		Regeneration	1.85	2.16%	
Ngel Nyaki (south)	2310	Deforestation	-23.11	-1.45%	-0.75%
		Regeneration	11.19	0.70%	
Ngel Nyaki (north)	1196	Deforestation	-7.75	-1.57%	-0.22%
		Regeneration	6.67	1.35%	

3.4.2.4 Forest regeneration and forest loss between 2000 and 2009

In this time period the visual impression is that of vast deforestation, especially in the Kurmin Danko area, but also in Ngel Nyaki (north), the Fulani properties, southern Ngel Nyaki (south) and in the north of the plateau area (Figure 3-12). Centres of regeneration are found in the centre of Ngel Nyaki (south), Yelwa township and in the very south-east of the plateau area.

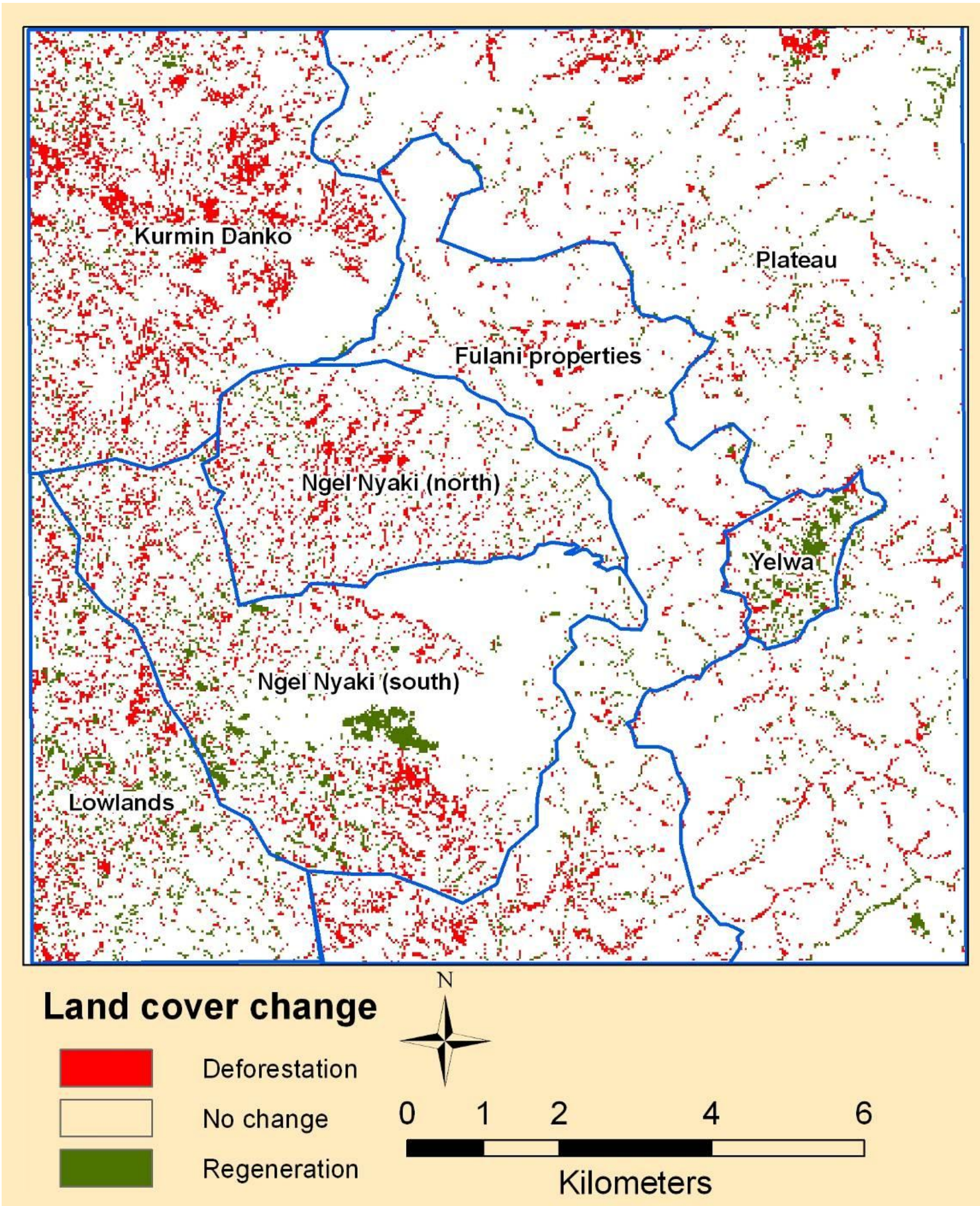


Figure 3-12: Deforestation and regeneration between 2000 and 2009

A quantification of land cover conversion rates shows overall very high rates of deforestation in all subdivisions. Only in Yelwa Township does the regeneration rate exceed the deforestation rate and result in a high land cover conversion towards the forest class. Comparing the plateau with the Fulani properties, similar deforestation rates can be observed (6.30% and 6.92%), however, regeneration is considerably lower in the latter (2.09% vs. 3.29%). When land conversion in the Kurmin Danko area and Ngel Nyaki (south) is compared, it is apparent that Kurmin Danko has higher rates of deforestation (3.29% vs. 1.65%) while at the same time exhibiting a lower rate of regeneration (0.55% vs. 1.20%). Ngel Nyaki (north) lies in between these two subdivisions in terms of deforestation and regeneration rates. The deforestation rate is as high as in Kurmin Danko, while the regeneration rate is almost as high as in Ngel Nyaki (south). The lowlands exhibit a higher deforestation rate (3.93%) than Kurmin Danko or Ngel Nyaki, although not as high as the plateau or the Fulani properties. However, at the same time this subdivision displays a high rate of regeneration (2.61%), in fact the second highest after the plateau area, when Yelwa as a semi-urban area is excluded from the comparison.

Table 3-12: Deforestation and regeneration between 2000 and 2009 by subdivision

Subdivision	Area [ha]	Type of change	Annual conversion		Net annual conversion
			[ha]	[%]	[%]
Plateau	5251	Deforestation	-26.69	-6.30%	-3.02%
		Regeneration	13.91	3.29%	
Kurmin Danko	2249	Deforestation	-45.23	-3.45%	-2.90%
		Regeneration	7.25	0.55%	
Lowlands	1284	Deforestation	-17.77	-3.93%	-1.32%
		Regeneration	11.80	2.61%	
Fulani properties	2493	Deforestation	-20.50	-6.92%	-4.83%
		Regeneration	6.20	2.09%	
Yelwa	261	Deforestation	-2.78	-3.57%	3.99%
		Regeneration	5.89	7.56%	
Ngel Nyaki (south)	2310	Deforestation	-23.72	-1.65%	-0.45%
		Regeneration	17.27	1.20%	
Ngel Nyaki (north)	1196	Deforestation	-16.50	-3.44%	-2.49%
		Regeneration	4.57	0.95%	

3.5 Discussion

3.5.1 Land cover classification

3.5.1.1 Limitations

The land cover classification that was performed faced several difficulties, especially the classification of the older Landsat imagery. In many previous studies, it has been shown possible to classify the landscape into 15+ land cover classes. Often even a distinction between multiple crop classes, grassland classes and forest classes were achieved. However, these studies required intensive ground truthing fieldwork, additional ecological knowledge as well as detailed and reliable ancillary data to realise this detail (Petit 2001; Brandt *et al.* 2002; Aaviksoo 2008; Antwi, Krawczynski & Wiegleb 2008). For this study, the only data available for the earlier time steps of 1988 and 2000 were the Landsat images and the written reports of Frantz (1981), Hurault (1998), Bawden and Tuley (1966) and Chapman (2001; 2004). No data is available for this region that would lend itself for groundtruthing and assessing classification results. However, to overcome this limitation, the classification detail has been scaled down to only distinguish between three classes with very different reflectance characteristics, which should result in a very accurate classification (Radeloff, Mladenoff & Boyce 2000).

Another setback was the late acquisition of the QuickBird scene due to adverse cloud presence, so that the imagery arrived after the field season was already completed. Hence the QuickBird imagery and classification could not be ground truthed by fieldwork. This limitation was overcome by using QuickBird's panchromatic band for ground truthing coupled with my familiarity of the study site. Many past studies have used aerial photography to ground truth historical satellite data (Shalaby 2007; Aaviksoo 2008; Alemayehu *et al.* 2009) because of its superior detail. Brandt *et al.* (2002), however, suggest that the 1m resolution of IKONOS imagery comes close to the detail delivered by aerial photography. This, of course, is even more true for QuickBird's 0.6m resolution panchromatic band.; Finally, Heatwole (2007) successfully demonstrates the use of this band for ground truthing and classification accuracy assessment.

Additional to these problems, the narrow spectral bandwidth of QuickBird imagery (only four bands) limited the detail that could be achieved with the classification. In this study, only the following classes were able to be discerned: forests, grassland, bare soil, kikuyu grass, recently burnt areas and scrubland / tall grasses. Agricultural land and (grass thatched) roofs were not able to be distinguished from dry Sporobolus grassland. Rocks and open savannah and roofs can also not be discerned from grassland. This is probably due to the limited extent of these features and therefore significant spectral blurring of these features with the dominant surrounding feature (grassland). The same holds true for cattle herds. Asphalt roads, due to their dark appearance, were indistinguishable from recently burnt areas. Also forest edge vegetation, bushes and long grasses that hold more moisture could not be further separated although this class was able to be separated from the senescent Sporobolus grass and forest vegetation. These difficulties in differentiation have also been reported in other studies in similar environments. Read *et al.* (2001) for example show that at least a mid-IR band is needed for good separation between pasture and agricultural land. Furthermore, Kuemmerle (2005) found open savannah, farmland and residential areas difficult to differentiate from grassland due to their similarities in spectral reflectance.

The forest class in particular was impossible to classify into further sub-categories. Although the QuickBird image showed a clear difference in texture between different forest patches, their difference in spectral reflectance was not significant enough for the classification algorithm to differentiate between them. Powell (2004) also reported difficulties in visually separating secondary forest and old growth forest, which limits the use of ground truthing via remotely sensed images. An appropriate ecological field study committed to sampling different sub-classes and adding texture based classification methods to the spectral classification method used here would therefore be highly recommended in this setting. However time constraints prohibited the use of these approaches in this study.

3.5.1.2 Discussion of results

When comparing the plateau with the Fulani properties adjacent to the reserve, it has been shown that these areas have very similar vegetation characteristics. The fact that the plateau has less recently burnt areas could mean that the Fulani living there cannot burn as much of their land as the Fulani living close to the reserve. As burning is used to stimulate the growth of nutritious green flushes but reduces the quantity of food available for cattle, it can be expected that those Fulani that have extended their pastures into the reserve can afford to exchange quantity feed for quality feed.

The high percentage of recently burnt areas in the lowlands indicates a high level of management while the fact that all burns showing up in the classification are late burns could mean that in this area fire is used as a means to fight scrub encroachment into the rangeland rather than to encourage green flushes.

The vegetation characteristics of Ngel Nyaki (north) compared to the lowlands could point to the following ecological mechanism: Ngel Nyaki north faces high grazing pressure during wet and dry season alike, therefore regeneration of shrubs and pioneer trees is kept low. In the lowlands, grazing pressure during the dry season is highest when herders from the plateau are grazing in this area while grazing pressure during the wet season is kept low due to the occurrence of Tsetse borne trypanosomiasis. Hence shrubs and pioneer trees have a chance to regenerate, which is countered with fire by the graziers during the next dry season. At the same time, Ngel Nyaki (north) shows vegetation characteristics somewhere between that of Ngel Nyaki (south) and the adjacent Fulani properties. This could be interpreted as a sign of the encroachment of rangeland management practices into the Forest Reserve. The fact that other, non-pastoralist people are living in the lowlands can also be expected to modify the vegetation class thumbprint, so that not all differences can be explained solely by the pastoralists’ actions. As can be seen from the example of Yelwa, the shrub & tall grass class as well as the tree class is much more prominent there than on the Fulani properties, due to different livelihood strategies.

When the two forest-dominated areas, Ngel Nyaki (south) and Kurmin Danko, are compared, the larger extent of grasslands in Kurmin Danko could indicate higher grazing activity in Kurmin Danko than in Ngel Nyaki south and hence point to a transition from a protected area to an area managed as rangeland.

The land cover characteristics in Yelwa are linked with the dominant land use there. Long grasses are grown along farm boundaries and used for roof thatching. Situated around Yelwa is a large extent of the villagers' fallow farms on which at this time of year long grasses, Yom, other shrubs and perennial crops like cocoyam and cassava grow. Eucalypt, tea and coffee plantations as well as prolific banana trees explain the high tree cover.

The land cover classes encountered in the study site are mostly representative for tropical montane climatic zones around the world. In areas of higher elevation that still allow tree growth, usually dry, moist and wet montane forests can be found (Fox 2005), depending on precipitation. Often wide areas are covered by grassland, forming a landscape mosaic of forested areas, open grassland and savannah areas of varying tree densities (Kintz, Young & Crews-Meyer 2006; Killeen *et al.* 2008). Depending on local disturbance regimes, scrubland is more or less common (Nyssen *et al.* 2004). The burnt grass category resembles extents of burnt grass, which is commonly used as a pasture management tool in tropical montane grasslands where cattle rearing is a major livelihood strategy (Kintz, Young & Crews-Meyer 2006; Farley 2007). The bare soil class has in some cases been used to identify areas of degradation through overgrazing or other unsustainable land use practices (Nyssen *et al.* 2004). The existence of localised patches of differing grass species (Kikuyu grass in this study area) is a local peculiarity, which is strongly associated with intense cattle trampling around herders' huts. Similar observations have not been reported in other montane locations as far as I am aware.

Those areas that are under formal protection (Ngel Nyaki and Kurmin Danko) have a relative high forest cover, which can be expected as an official protection status is often able to curb large scale deforestation in such an area (Kintz, Young & Crews-Meyer 2006; Garcia-Barrios, Speelman & Pimm 2008).

Also areas (Yelwa and to a limited extent the lowlands) where local people plant tree crops as well as crops that fall under the 'tree' class, like fruit trees, coffee and tea appear more forested in the classification results. These types of land cover around villages in similar climatic situations are typical and have been described by Farley (2007) and Imbernon (1999).

The lowest natural forest cover is found in areas of high intensity grazing (Fulani properties and plateau) or near population centres (Yelwa). This is a trend for natural montane forest distribution commonly recognised in the literature (Imbernon 1999; Cayuela, Benayas & Echeverria 2006; Arredondo-Leon, Munoz-Jimenez & Garcia-Romero 2008; Izquierdo 2009).

3.5.2 Land cover change analysis

3.5.2.1 Limitations

As has been explained in the previous chapter, an assessment of classification accuracies of the older images has not been possible. Therefore, in order to get classification results as accurate as possible, only a very simple classification with three classes has been carried out. When interpreting detected change in land cover it is important to keep in mind that the data on vegetation change is derived from reflectances in different light spectra. Therefore, the replacement of an old growth stream bank forest, for example, with thick *Afromomum* vegetation or secondary forest may not be picked up by a simple classification procedure as both vegetation types reflect in similar spectra. Furthermore, eucalyptus plantations that are established in place of native forest are also indistinguishable from native forest. Therefore errors in interpretation of this kind can be expected to have resulted in an underestimation of the extent of native forest loss or an overestimation of its regeneration.

Another limitation for the analysis of different subdivisions was posed by the absence of objective boundaries for the lowlands and the Kurmin Danko area. While the boundary between the plateau, and Kurmin Danko was given naturally by the topology it was not clear where the boundary between Kurmin Danko and the lowlands was supposed to be drawn. Therefore a subjective decision has been made as to its location. Similarly, the boundary between the lowlands and the Fulani properties provides some room for error as the approximate boundary of T's property was only pointed out from a distance and transferred to the map later as there was no opportunity to ascertain the location of this boundary any further.

3.5.2.2 Discussion of results

As has been described in chapter 1 (pp 13-5) and section 2.2.4.3 (pp 49/51), local people living inside the reserve were evicted from the reserve between 1969 and 1974. Since then no major logging or agricultural conversions have been recorded. In this region the major activity leading to deforestation, habitat destruction and habitat fragmentation is the ongoing grazing and burning throughout a large proportion of the reserve (Chapman 2008). Apart from that, the reserve experiences very few disturbances. Hence a simplified interpretation is acceptable where the disappearance of forest cover can be attributed to the presence or absence of cattle and burning.

This observation would be in line with the descriptions of Chapman and Chapman (2001), who propose the following mechanism of riverine forest degradation: cattle trampling at the forest edge leads to light penetration into the understory. Thereby grasses can invade the forest. When these grasses become senescent during the dry season, the Fulani burn the pasture. These fires, which in part are laid late in the dry season[8], can now advance into the forest and lead to a widening of the gap in canopy cover. This in turn allows increased light penetration. Hence a positive feedback

[8]Due to increased fuel load and reduced residual moisture in the vegetation and forest litter, late grass fires burn hotter and are able to damage trees and saplings that are not fire resistant.

loop is created that diminishes forest cover and riverine forest in the area quickly. Other studies have also confirmed the destructive nature of intensive grazing and burning to montane forest communities (Hurault 1998; Omotayo 2003; Afolayan 2008). Hurault (1998) agrees that severe trampling impedes regeneration and hot grass fires can destroy the remains of an already degraded gallery forest. Furthermore, Omotayo (2003) explains how frequent bush fires set by Fulani herders can destabilise the ecosystem. The significance of timing the annual burning on vegetation cover is emphasised by Afolayan (2008). It is pointed out that early burning supports the growth of saplings and small trees, while late fires destroy them and suppress regeneration. Observations of burning activities during the study period can be interpreted in this context: The majority of burning inside and outside the reserve has been observed at the beginning of the dry season. Fulani herders explained that this was done to supply cattle with nutritious green flushes in the dry season. However several fires were also seen throughout the reserve and along the riparian forests outside the reserve during the middle and towards the end of the dry season. These burning activities werenot commented on by Fulani herders, but were very likely to be pasture improvement[9] or pasture extension measures[10]. The observation of two fires set inside an existing forest patch in January 2009 strengthens this notion.

The fact that the regeneration rate in the lowlands is 270% as high as the regeneration rate in Ngel Nyaki (north) could signify that the majority of forest regeneration happens during the wet season, when the Fulani cannot graze the lowlands (because of Tsetse borne diseases) but are able to continue grazing in northern Ngel Nyaki. This scenario would explain the rapid decrease in forest cover in this Ngel Nyaki (north). During the dry season the reserve is grazed above carrying capacity (see chapter 5), widespread burning late in the dry season clears shrubs, saplings and small trees and during the wet season regeneration is inhibited by cattle trampling and grazing.

In section 3.4.2.1 it has been established that the remaining forest and the extent of streambank vegetation are shrinking. This is especially true in the northern part of the reserve, the Fulani properties, the Kurmin Danko area and the plateau area, where active deforestation has increased dramatically during the last decade.

Due to the long distance from the field station it was impossible to ascertain the reason(s) behind the large scale deforestation in the southern part of the reserve between 1988 and 2000. Concerning the northern part of the reserve, burning and grazing coincides conspicuously with forest cover reduction. Unfortunately, what has caused the spur in net-deforestation in the last decade remains unknown due to a lack of information about changes in the situation of the region.

In all subdivisions in the study area except Yelwa, deforestation occurred during the study period. The most significant period of deforestation was between 2000 and 2009 with very high deforestation rates in all subdivisions except Ngel Nyaki (south) and Yelwa. The amount of annual deforestation for the whole study area is within the

[9]Removal of encroaching woody species from the existing pastures

[10]Conversion of forest to grassland

deforestation bracket reported for deforestation hotspots in Africa and Asia (Achard *et al.* 2002). The change in each subset of the study site is very high and in some cases exceeds even the highest reported deforestation rates in the world (Ochoa-Gaona 2000). However this is most likely an artefact of investigating small subsets of a relatively small study site. As Redo *et al.* (2009) note, land cover changes tend to be of a higher amplitude the smaller the area under investigation is. The larger the area, the more conservative will estimations be due to the averaging effect of analysing larger landscapes. Ochoa-Gaona (2000) also state that land cover changes are not only dependent on the spatial extent that is studied, but also on the temporal extent. In their study of deforestation in Chiapas, Mexico, average annual deforestation rates were much lower (2.3%-2.6%) when considered over the whole time period compared to the individual time steps (up to 3.4%). This tendency was also found in the research conducted around Ngel Nyaki. Hence, the more time steps are available and the more evenly these time steps are distributed over the study period, the more insightful and better interpretable are the resulting deforestation rates.

The highest deforestation rates (4.8%) in my study of land cover change are found from 2000-2009 on the Fulani properties (total area 2493 ha). These rates are very high, but still within the rates reported in other studies in similar environmental settings (see below). When the total study site is considered (total area 15044ha) the highest deforestation rate is found at 1.9% between 2000 and 2009. When compared with other studies in tropical highlands this rate is still well within the expected deforestation rates commonly found in areas of high population pressures and intensive pastoral and ranching activities.

Studies in the tropical montane areas of Central and South America report average annual deforestation rates between 1.3% and 4.8% for 1975-1990 and 1990-2000 respectively for Chiapas, Mexico (Cayuela, Benayas & Echeverria 2006), 4.2 and 4.3% for 1967-1976 and 1976-1986 respectively in Los Tuxtlas, Mexico (Dirzo 1992), 0.46%-1.86% for 1974-1984, 1.1%-3.4% for 1984-1990 and 4.1%-5% for 1990-1996 in Chiapas, Mexico (Ochoa-Gaona 2000).

Most land cover change in tropical montane regions reported in the literature is driven by agricultural expansion (including livestock rearing) and intensification of production systems in areas of population growth (Ochoa-Gaona 2000; Cayuela, Benayas & Echeverria 2006; Arredondo-Leon, Munoz-Jimenez & Garcia-Romero 2008). These drivers are also present in the study area considered in this research, so it may not come as a surprise if similar trajectories of deforestation are found. A driver for land cover change not found around Ngel Nyaki is the large scale shift from subsistence farming towards cash crops. This shift had a major impact on forest cover in Southeast Asia according to Fox (2005).

Forest cover increase in Yelwa can best be explained by the forest transition theory (Rudel *et al.* 2005). As the village was shifted from within the reserve to its current location, natural forest resources dwindled and forest scarcity was experienced. This led to rapid, government supported establishment of Eucalypt plantations on the outskirts of the township (Korndoerfer 2010) similar to a situation found by Munoz-Villers (2008) in Veracruz, Mexico and by Farley (2007) in the Ecuadorian Andes.

Few studies report an increase in natural forest. However there are some reports where natural forest is regenerating. Where this land cover change is observed, the drivers responsible are usually: a decrease of rural population dependent on agriculture through rural urban migration or the successful creation of enough off-farm employment to pull people from marginal land (Izquierdo 2009). Falling commodity prices, which makes the farming of marginal land unviable can be another driver (Garcia-Barrios, Speelman & Pimm 2008). In this case there is a trend of abandoning marginal land on which forest can regenerate and increased intensification of arable land. Munoz-Villers (2008) found that forest regeneration is requires government led reforestation and conservation programs in conjunction with the abandonment of agricultural fields and pastures. In some cases the protection in reserves has led to increase in forest cover (Fox 2005; Kintz, Young & Crews-Meyer 2006) or at least to a slower rate of deforestation (Garcia-Barrios, Speelman & Pimm 2008).

Altogether, once converted natural forests are usually not recovered. Land use changes, even if leading to reforestation, usually are restricted to plantations of fast growing exotic species like Pine or Eucalyptus, which are favoured over native species (Rudel *et al.* 2005; Farley 2007).

3.6 Conclusion

The map of current land cover shows the different land cover characteristics within the different subdivisions of the study area. Differing land cover distributions have been linked to differing land use and land management in each area. It has been shown that the protected areas show obvious signs of use and management as rangeland.

The analysis of forest cover change showed alarmingly that the Ngel Nyaki forest is under threat. The northern part of the reserve, where frequent grazing and burning can be observed has shown accelerated forest loss, particularly during the last eight years. Throughout the reserve, primary montane forest is lost and replaced by secondary growth. Given the data for the last 21 years, it is highly unlikely that the forest in the reserve will regenerate under the current management regime of grazing and burning and possible further intensification driven by population increases.

In summary, pertaining to this section's goals, the following observations were made:

<u>Land cover</u>

- The land cover in the study area is typical for a tropical montane region and that land cover is closely related to dominant land use
- A large extent of the protected areas Ngel Nyaki and Kurmin Danko is regularly burnt and grazed
- A large extent of the Fulani properties as well as of the protected areas are subject to late burns, which potentially destroys young saplings and hinders succession
-

Land cover change

- A large extent of the protected areas Ngel Nyaki and Kurmin Danko are subject to rapid deforestation
- Different subsets of the study area demonstrate different rates of land cover change
- The highest rate of deforestation is encountered on the Fulani properties and on the plateau in general
- Regeneration rates are much higher in the lowlands than in the protected areas, which hints at the importance of a relatively undisturbed growing season for regeneration
- Deforestation rates are very high especially during the last decade
- Yelwa Township is experiencing a forest transition, however, at the moment reforestation happens only in plantations of exotic eucalypts.

Chapter 4: Exploration of local Fulani pastoral management systems

4.1 Introduction

Conflict between pastoralists and conservationists about the use of protected areas is a widespread issue, not only in Africa but throughout the world (Maikhuri *et al.* 2001; Mishra 2002; Michalski *et al.* 2006). In section 1.5.1 it was established that participation and involvement of local communities in conservation planning is instrumental to the long term success of a conservation project (Brandon & Wells 1992; Hulme & Murphree 1999). This section seeks to address the call from several authors (e.g. Anderson & Grove (1989), Abbot *et al.* (2001), Henson *et al.* (2009), Reid *et al.* (2009)), to take into account the livelihood needs of local pastoralists in the vicinity of protected areas, using Ngel Nyaki Forest Reserve (NNFR) as an example. The activities of the Fulani pastoralists in the vicinity of Ngel Nyaki Forest Reserve have the power to directly affect the conservation success of the reserve. Therefore, features directly linked to the livelihood strategies of the local Fulani were investigated with major research questions centred on animal and pasture management practices, grazing intensities and reasons for grazing within NNFR.

4.1 Aims and goals

The aims of this section were to (1) establish an overview of the local social structures and power dynamics, (2) obtain an understanding of the current animal and pasture management practices in and adjacent to the Ngel Nyaki Forest Reserve and (3) understand why the Fulani graze in the Forest Reserve. This information was obtained through a series of interviews with the local Fulani herders, landowners who employ these herders and other people deemed suitable to provide relevant information.

The information from the interviews is then analysed to further the understanding of the cultural context of grazing in and around the reserve.

4.2 Methods

4.2.1 Placing social research within a natural sciences thesis

As this chapter, presenting social research, is located within a larger natural science dominated thesis, this chapter follows the structural conventions of the natural sciences. I am aware that in a pure work of social research, a greater emphasis would be placed on the researcher’s positionality and the implications this may have for the research results. Also it is quite common in the social sciences to identify the theorists from whose perspective the results are interpreted. As this chapter is only one of many nested within a bigger work, an in-depth discussion of this matter is not possible. However, I believe that these shortcomings do not considerably obstruct the establishment of a rather general knowledge base of the pastoral practices and social structure of the Fulani in the study area. I also acknowledge that more focussed research would have to be done to adequately describe the lived reality of a Fulani living in this area.

4.2.2 Ethical issues

In order to protect the anonymity of interviewees the name of each interviewee has been substituted by a number (herders and other interviewees) or a capital letter (land owners). The coding for individuals has been kept identical for all chapters in this thesis. When referencing to particular interviews throughout this section the interview identification number (IID#) is given.

4.2.3 Interviewees

Four groups of people were interviewed (Table 4-1). The first group comprised all interviewed Fulani herders (IID# 1-16). The second group consisted of landowners who owned land adjacent to or in the vicinity of the northern part of the reserve (IID# 17-19). Specific selection criteria for potential interviewees in groups one and two were: access, close proximity to the reserve, utilization of the reserve and willingness to participate. Interviews with members of this group were held through a translator.

The third group of interviewees were individuals who were not directly related to my research question. The group comprised both Fulani and Mambilla tribesmen, all but one were NMFP field assistants and all had knowledge of cattle farming in the region, many as a result of having family members who were landowners. The Fulani in this group were chosen as interviewees because of their personal experience with cattle management in the area. They also knew many of the herders and landowners personally, which helped with gaining access to additional interviewees as well as with identifying property or herd ownership. The two field assistants of the Mambilla tribe were chosen because they both have good relations with many of the herders and land owners in the study area and are very knowledgeable about the goings-on in the region. All interviewees in this group were chosen for their accessibility, their knowledge of local pastoral management and their knowledge of English which made interviews without intermediary possible.

In order to get an official point of view, additionally two public servants were interviewed, which make up the fourth group of interviewees (IID# 25-26).

Table 4-1: Individuals appearing in this study

<table>
<tr><th>Interview ID (IID#)</th><th>Group</th><th>Interviewee</th><th>Description</th></tr>
<tr><td>1</td><td rowspan="16">Group 1</td><td>16</td><td>Herder for Q</td></tr>
<tr><td>2</td><td>17</td><td>Herder for Q</td></tr>
<tr><td>3</td><td>18</td><td>Herder for R</td></tr>
<tr><td>4</td><td>10</td><td>Herder for G</td></tr>
<tr><td>5</td><td>7</td><td>Herder for G</td></tr>
<tr><td>6</td><td>9</td><td>Herder for G</td></tr>
<tr><td>7</td><td>8</td><td>Herder for G</td></tr>
<tr><td>8</td><td>19</td><td>Herder for G</td></tr>
<tr><td>9</td><td>4</td><td>Herder for D</td></tr>
<tr><td>10</td><td>20</td><td>Herder for O</td></tr>
<tr><td>11</td><td>21</td><td>Herder for T</td></tr>
<tr><td>12</td><td>22</td><td>Herder for T</td></tr>
<tr><td>13</td><td>23</td><td>Herder for T</td></tr>
<tr><td>14</td><td>6</td><td>Herder for N</td></tr>
<tr><td>15</td><td>5</td><td>Herder for E</td></tr>
<tr><td>16</td><td>24</td><td>Herder for T</td></tr>
<tr><td>17</td><td rowspan="3">Group 2</td><td>E</td><td>Owns cattle inside the reserve</td></tr>
<tr><td>18</td><td>R</td><td>Owns land adjacent to the reserve</td></tr>
<tr><td>19</td><td>U</td><td>Owns land near the reserve and cattle inside</td></tr>
<tr><td>20</td><td rowspan="7">Group 3</td><td rowspan="2">25</td><td rowspan="2">Nephew of a cattle/land owner near Mai Samari</td></tr>
<tr><td>21</td></tr>
<tr><td>22</td><td rowspan="2">26</td><td rowspan="2">NMFP field assistant and son of cattle owner</td></tr>
<tr><td>23</td></tr>
<tr><td rowspan="3">24</td><td>27</td><td>NMFP field assistant (Mambilla)</td></tr>
<tr><td>28</td><td>NMFP field assistant (Mambilla)</td></tr>
<tr><td>31</td><td>Son of P and NMFP field assistant</td></tr>
<tr><td>25</td><td rowspan="2">Group 4</td><td>29</td><td>Taraba state government official</td></tr>
<tr><td>26</td><td>30</td><td>Local authority forestry official, Gembu</td></tr>
</table>

4.2.4 Language Barrier

To overcome the language barrier between myself and the interviewees, a Fulani interpreter was employed where needed to translate between English and Fulfulde, the language of the Fulani pastoralists. The Mambilla and public servant interviewees had a reasonable good command of English. Therefore these interviews were usually conducted in English without the need for an interpreter.

4.2.5 Interview and Observation Style

In contrast to the quantitative methods often used when scoping stakeholders' opinions (De Lopez 2001; Bandara & Tisdell 2003; Weladji, Moe & Vedeld 2003; Wattage & Mardle 2005; Strager & Rosenberger 2006), rapid appraisal is a qualitative methodology that offers very specific insights, helping to define what the primary issues are rather than how many people are affected by them (Murray *et al.* 1994). Due to limited time available in the field, the lack of an appropriate interpreter for conducting in-depth interviews and the lack of an established knowledge base, the rapid appraisal methodology was considered appropriate to explore the main narratives encountered when conversing with local Fulani.

The interviews were undertaken in an informal conversational interview style (Patton 2002). Some interview guide questions were established as suggested by Patton (2002), so that the interview sometimes showed characteristics of a semi-directed interview (Huntington 1998). This approach has been successfully used in several studies that researched traditional ecological knowledge among indigenous people (Huntington 2000; Nichols *et al.* 2004; Pearce *et al.* 2009).

This interview style emerged out of necessity. It was initially proposed to use structured interviews, but after a trial run this plan was discarded as the process of taking notes, writing and reading was eyed with great suspicion by the mostly illiterate interviewees. Furthermore, direct questions relating to the research topic outside of a conversational context had the result that the interviewees quickly withdrew and ended the conversation. However, there were a few exceptions to this. IID# 20 received a university education and hence was familiar with the process of interviewing and a semi structured interview style was used. Two other interviewees (IID# 22 and 23) were employed as field assistants and therefore were comfortable with students asking questions and taking notes. As they were available most of the time at the field station, there were several short, unstructured, but focussed interview sessions, whenever time allowed and the information gathered was noted down immediately.

All the other interviews were unstructured and kept in a casual conversational style. In conversations, where a translator was needed, IID# 21 (the translator) was asked to keep up a conversation with the subject in Fulfulde, while I only occasionally interjected to ask what had been said. If the current trajectory of the conversation seemed to yield the required information the flow of conversation was not disturbed, if not, I asked some intermittent questions to steer the conversation in the required direction. These questions were then answered more or less directly. This method yielded the most information in this setting.

Immediately after the interviews, I received an oral summary of what had been said from the translator. Topics that were of special interest were expanded upon further. Additionally, the translator was able to give a personal evaluation of the truthfulness of the content given by the interviewee and conveyed additional information about the interviewees' emotional state i.e. if the interviewee was relaxed, nervous, hesitant, angry or intimidated during the conversation. The obvious limitations of this approach are (1) that the translator may have forgotten some important details or failed to ask questions that would have yielded valuable data and (2) that the translator had a limited ability to judge people's behaviour and identify possible untruths. It is also possible the translator would not have conveyed information to me that he deemed a risk to his own position, although I am unsure of what such information would have been. In the process of collating the information with the translator, I aimed to display neutrality towards the information gained, in order to avoid pressuring the translator into a particular direction and thus biasing the results.

The answers given by the interviewees were noted down in a notebook during these discussions with the translator.

In order to complement the information gained from the interviews, observations were made concerning cattle grazing, cattle locations, cattle distributions and herders' living conditions continuously throughout the study period. All observations were collected on a casual basis by living in the project setting. Whenever an observation was made, questions about the observation were immediately asked of local people present at the time, to better understand this particular observation in its context. These conversations often yielded a wealth of information and gave an important impetus for topics to be addressed in subsequent interviews.

4.2.6 Interview Locations

The Fulani herders were interviewed in the pastures or the reserve where they grazed the cattle, while landowners were interviewed at their compounds. Interviews with the Mambilla field assistants were held at the NMFP field station. The interview with the Taraba State government official IID# 25 was conducted at his compound and on an excursion to Kakara. The interview with IID# 26, the local government forestry official, was conducted at his office in Gembu.

4.2.7 Topics addressed in herder interviews

Table 4-2: List of questions the herders were asked

Question ID	Question	Notes
I	What is your name?	
II	What is your boss' name?	
III	Do you have many or few cattle?	Many herders claimed not to know the number, so this question was omitted after a while and replaced by counting
IV	Where do you give water to your cattle?	This question was asked to find out the current importance of the reserve pertaining to the natural resource "water"
V	Where do you graze in the wet/dry season?	This question sought to prompt herders to tell if they are using the reserve seasonally or year round and whether they migrate to the lowlands
VI	When do you come back?	Clarifying the exact number of months the reserve is grazed by an individual herder, if the herder goes on transhumance
VII	How long have you been living in this place?	
VIII	Do you have a farm?	The following questions were asked to collect data about the living conditions of the herder
IX	If not, why not?	
X	Do you own cattle yourself?	
XI	If no, would you like to own your own cattle?	
XII	Is it only you that grazes in this area?	This question aimed to elucidate the compartmentalization of the reserve grazing area
XIII	How often do you come here (reserve)?	It has been observed that many herders do not come to the reserve every day.
XIV	Why do you take your cattle here?	An important question that was intended to help reveal the benefits of grazing the reserve from the perspective of a herder

4.2.8 Data Verification

From differences in culture and the language barrier arose difficulties in making sense of the many pieces of information that were gathered. Hence, great care had to be taken to verify the collected data by triangulation of information (Heaver 1991). The method followed the general principles of the rapid appraisal methodology (Beebe 1995) although undertaking the research as part of an MSc thesis precluded the use of two or more researchers being involved in the information gathering process.

General information, such as payment structures, duties, grass burning strategies, transhumance patterns, grazing patterns etc have been noted down as fact only if verified by at least two other interviewees. Personal experiences that were reported and management strategies that are unique to individual interviewees were, of course, not able to be triangulated and could only be evaluated by checking against observations and coherence with previous conversations (with the same herder).

General information gathered in one interview was subsequently carried to the next interview and questions were asked about the interviewee's opinion about these different pieces of information. Often, neighbouring herders visit each other, are related or live in the same compound and hence are informed about what the other herders are doing, their herding strategies, when and where they go on transhumance, where and how often they water their cattle, where they graze their cattle, whether they are happy with their employer, whether they have children, whether they are married etc. Consequently, a lot of knowledge was gained by asking interviewees questions about neighbouring herders and cattle owners.

To avoid the danger of interviewees indiscriminatingly confirming the information they were given and hence confounding the results of the verification process, the interviewee was engaged in a conversation about this topic through which the interviewee's opinion became clear.

In addition, data that at the time still had to be verified was given to the translator who, during the interview was able to verify and clarify pieces of information. Other people deemed suitable to verify and clarify gathered information and explain details were the Mambilla informants, because of their relatively good command of English, their good relations to many of the herders and landowners in the study area and their knowledge about the goings-on in the region. Furthermore, they were both working for the NMFP and were used to relaying information to western scientists. As previously mentioned, the information given by these two informants also has its biases and can not be used as the only means of verification although higher credence has been given to information also confirmed by these informants.

4.2.9 Method employed to interpret and present data from observations, literature and interviews

In order to distinguish data from (1) interviews, (2) observation and (3) literature, the type of data is referenced after the piece of data presented. Data from interviews carries the interviewee ID number (IID#). Data from observation is referenced as ‘pers. obs.’ (pers. obs.) and data derived from literature, is referenced in Harvard style as in the rest of this thesis.

4.3 Results and discussion

4.3.1 Discussion of methodology

Despite the use of a translator, at times great difficulties were encountered concerning the transfer of information. This was partly due to the translator’s limited knowledge of the English language and to significant cultural differences which often made it difficult to convey the meaning of questions and to make sense of answers given. For example, questions that seemed reasonable to me as a researcher from a western background did not always make sense to the local people, while the converse was also often true regarding responses from local people. Questions containing “why” were often met with incomprehension and lengthy explanations were required. From my understanding, it is more common in Fulfulde to make statements or ask rhetorical questions which the conversation partner then “answers” by making counter statements, which may or may not be in direct relation to the “question”. For example, when leaving the field station the field assistants more commonly asked: “Are you going?” when they wanted to know *where* I was going, leaving it up to me to tell them my destination.

4.3.2 The Fulani Pastoralists of the Mambilla Plateau

4.3.2.1 Pastoral production systems

The Fulani of the Mambilla Plateau have finished the transition from traditionally nomadic to transhumant livelihoods, while many are undergoing another transition from transhumant pastoralism to agropastoralism and ranching systems (Danburam 2004). This transition is most likely due to improved infrastructure since the construction of an asphalt road crossing the plateau and the increased importance of market forces on livelihood decisions (Frantz 1981; Hurault 1998). Blench (1984) sees another reason for the tendency towards settled agropastoralism on Mambilla in the history of Fulani political dominance (see chapter 1).

It may not come as a surprise that the traditionally rather conservative Fulani culture (Basehart 1977) struggles to adapt to a sedentary lifestyle, which is accompanied by the usual side effects: loss of traditional culture, erosion of traditional social structures and environmental degradation (Danburam 2004).

4.3.2.2 Differentiation between Fulani groups

The Fulani separate themselves into two groups, the Mbororo (Bush Fulani) and the Fulani Wuro (Town Fulani) (IID# 20,21,22,23). The Mbororo tend to live in settlements away from established villages and live a more traditional life on their property or family compound amidst their animals. Their main (and frequently only) source of income is through cattle trading. Trading is most prominent in the local markets, but cattle are also often transported by truck to

Jos or Onitsha (Figure 4-1) where good prices can be realised (IID#18). To reach these locations by truck only takes one day, while to cover this distance on foot with a herd of cattle would take several weeks.

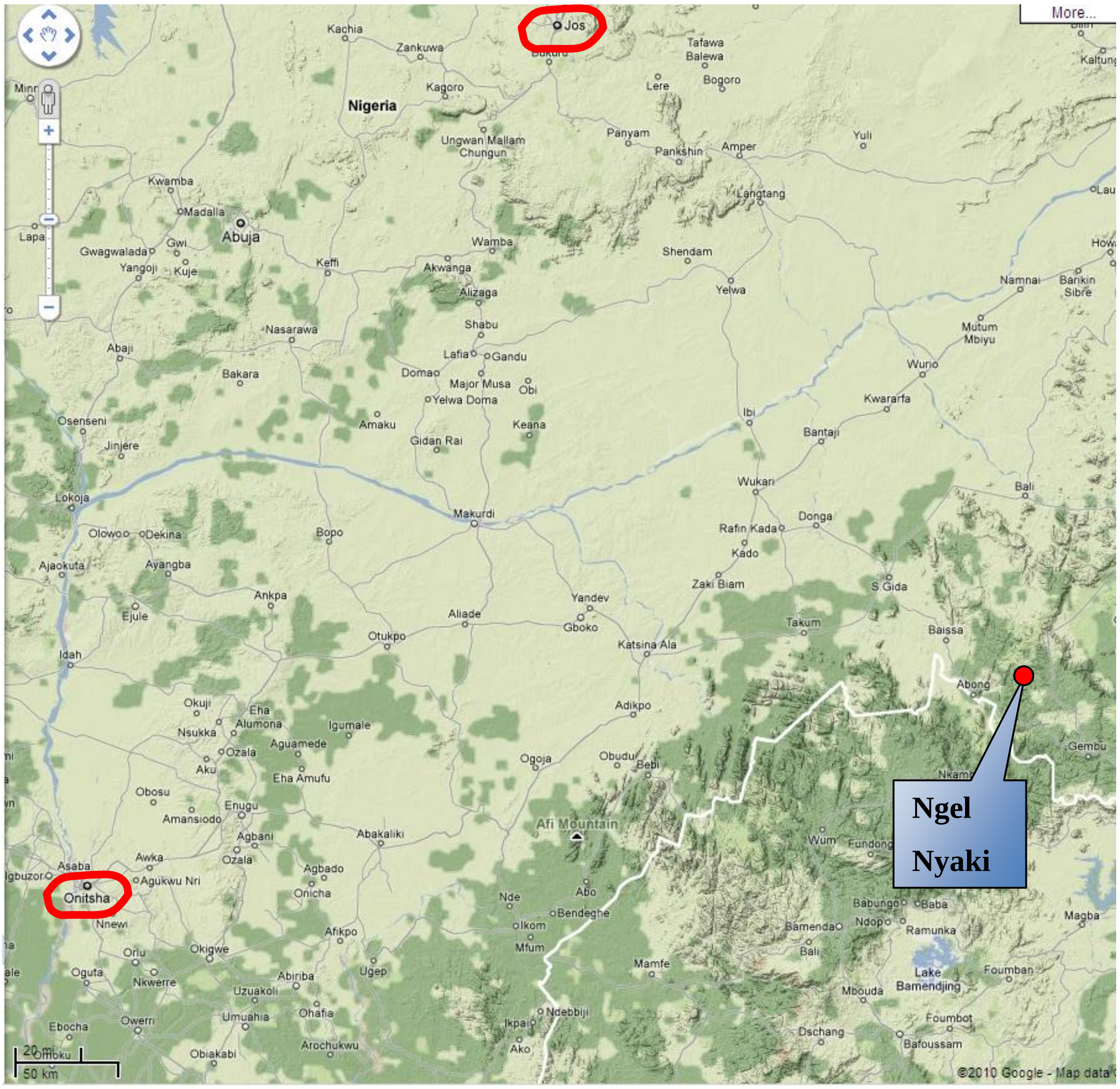


Figure 4-1: Locations of Onitsha and Jos in relation to Ngel Nyaki (Map derived from Google Maps)

The Town Fulani usually live in established villages and may or may not own a property and livestock outside the township. Often, Fulani who lost their cattle through misfortune (e.g. disease, war) or mismanagement (e.g. living above their means) seek other livelihoods and move to towns. Additionally, children of Mbororo families, who cannot or do not want to work on the property and follow traditional livelihoods, seek employment in villages and towns. Town Fulani are more likely to have finished some form of formal education than their counterparts from the "bush" (IID# 20,21,22,23, pers. obs.).

Apart from the differences between Fulani groups marked by differences in occupation, there are also sub-groups within the Mbororo group (which have not been considered in this research due to time limitations). Natural resource use differs between Fulani groups and sub groups, which must also be duly considered in participatory conservation project planning (Green 2005).

4.3.2.3 Land tenure

Although the *cattle owners* (in contrast to *cattle herders*) in the study area are settled agro-pastoralists, owning clearly defined and demarcated properties, the commonly made distinction between transhumant and agro-pastoralist Fulani is blurred. The pasture is often managed through a ranching system with fenced properties, however, in the dry season most cattle owners send some of their herds down to the lowlands where they hold grazing permits. This means that although the cattle owner is sedentary, some of his herders live a seasonally transhumant lifestyle while other herders follow agro-pastoral livelihoods all year round (IID# 20,pers. obs.). In contrast to the Fulani landowners, the herders have no land rights, they are given the permission to build a hut or to farm a patch of land but have no ownership and can be made to leave at the landowner's will (IID# 1,5,18,20,21). Understanding the differences in tenure between different Fulani socioeconomic groups and hence their power relations is integral to achieving thesis goal three, as these different groups most certainly have different interactions and sentiments towards the reserve.

In the study area, popular destinations for lowland dry season grazing are Mai Njebbe (to the south-west of Ngel Nyaki Forest Reserve) and Dujire (to the north-west of Ngel Nyaki Forest Reserve), destinations that can be reached within one to two days walk from the NMFP field station[11] when accompanied by a herd of cattle. Without animals these destinations can be reached within four to six hours walk at a fast pace (IID# 21,22,23,12,pers. obs.). One interviewee told me that grazing permits were increasingly hard to get due to an increase in cattle from other lowland areas (presumably from further north) at these traditional dry season grazing locations (IID#20).

In contrast to the plateau, in the lowlands the Fulani can only hold grazing permits for an area, not the right of occupancy. That the Fulani can receive the right of occupancy for their pastures is a feature unique to the Mambilla Plateau, not found elsewhere in Nigeria (IID# 25). Some interviewees stated that the Fulani have managed to turn their grazing permits into a right of occupancy by extensively bribing local or state government officials on the plateau. This angers some of the indigenous tribes, who are struggling to have enough arable land to pursue subsistence farming, the system for which the local land tenure system was originally designed (IID# 22,25,26).

The available arable land on the plateau is becoming increasingly rare and expensive. The reasons for this development are mainly found in the appropriation of land by urban elites (Danburam 2004) and the geometric population increase among all tribes of the plateau (Korndoerfer 2010). Hence, it is not surprising that some Fulani fear that the right of occupancy for their property may be revoked in the future. This fear may not be unfounded as relatively more people from indigenous tribes are receiving formal education and enter the workforce in decision-making positions

[11]These destinations and the migration routes are mapped in chapter 5

as civil servants or lawyers (Danburam 2004), and as stated previously, the feeling among these tribes is that the right of ownership should not have been given for the pastures in the first place (IID# 22,25).

4.3.2.4 Social structures and power dynamics

4.3.2.4.1 Discrimination between herders and cattle owners

On the Mambilla Plateau, unlike in other areas of the world (Blench 2001), the pastoralists are not marginalised people, but wealthy businessmen with significant influence in local, state and federal government (IID# 20,22,25,26). At least this holds true for the owners of cattle, as in the study region a marked distinction has to be made between cattle owners and cattle herders (Table 4-3).

Cattle owners themselves can be divided into three distinct groups: local Fulani cattle owners, absentee Fulani cattle owners and absentee non-Fulani cattle owners. Local Fulani cattle owners are prevalent around Ngel Nyaki Forest Reserve. Typically, local Fulani landowners on the Mambilla Plateau live in large family compounds (Fulfulde: *wuro ladde*), away from Mambilla villages. Some local Fulani cattle owners have a domicile in a nearby city in addition to their rural compounds, but they all set themselves apart from the other two types of cattle owners by living locally, at least part-time, in order to be able to frequently inspect their land and herds, and by personally attending markets and festivities, which also serve as a platform for local politics (IID# 20,22, pers. obs.). Absentee Fulani cattle owners are Fulani business men that do not live on the plateau. Often their main source of income comes from other forms of business or they additionally own land or cattle in other parts of Nigeria. Whatever their primary livelihood strategy, their common characteristic is to have chosen a more sophisticated domicile than the rural Mambilla Plateau. Absentee non-Fulani cattle owners are usually rich business men and high ranking public servants from anywhere in Nigeria who own land on the Mambilla Plateau, which is considered prestigious, and employ local herders to look after their cattle.

The common characteristics among all types of cattle owners on the Mambilla Plateau are that they employ herders to look after the needs of their livestock rather than tending to their herds themselves and that they wield significant political power. In the following text the term “cattle owners” is used to refer to the local Fulani cattle owners. Although a few people from other tribes in the wider region own cattle as well, the cattle owners in the study area are all of the Fulani ethnic group (pers. obs.).

Table 4-3: Main differences between herding and land owning Fulani in the study region summarising interview results

	Herders	Landowners
Professional relationship	• Employee	• Employer
Cattle ownership	• May own up to 7 or 8 head of cattle	• Often own several hundred head of cattle
Farming	• May be allowed to farm on the landowner’s land	• Often is given some of the produce farmed by the herder • Farm is owned by the landowner
Residential	• Lives in small homestead provided and owned by the employer • Many are seasonally transhumant	• Owns large family compounds, often in multiple locations (towns) • Sedentary
Land tenure on the Mambilla plateau	• No property ownership	• Owns large extents of rangeland
Land tenure in the Lowlands	• Herders are sent there on transhumance during dry season	• Hold grazing permits there
Responsibilities	• Tick removal • Safeguarding cattle • Keep cattle in good health • Take cattle to waterhole • Take cattle to the appropriate grazing locations • Burning the grassland • Drive cattle to a location where the owner can inspect the herd • Take cattle to markets	• Deciding on who and how many herders to employ • Deciding on herders' wages • Deciding on who to send on transhumance • Deciding on herd composition, breeding, buying and selling of animals • Deciding on market to buy/sell animals from/to • Obtaining grazing permits • Obtaining burning permits • Obtaining permits to fell trees along streamsides

The separation of cattle owners and cattle herders emerges automatically from disparities in socioeconomic class and sphere of activity. While the cattle owner decides on the size of a herd, the breed of animals, the time of grassland burning and the sale or purchase of animals, the herder’s obligation is to ensure that the animals are healthy and well fed. Differences in socioeconomic class typically manifest thus: Cattle owners, who are usually Muslim, typically have made the (expensive) pilgrimage to Mecca at least once and are often able to read and write in Arabic. Additionally, they own motor vehicles, multiple houses in different towns, mobile phones, generators and other luxury items, have multiple wives (up to four) and generally enjoy respect, influence and other signs of a high social status. Herders on the other hand usually own very few personal effects and are often not married. Those who are married rarely can afford to support more than one wife and never have more than 2 wives. They do not usually own their own property or farm. They are financially far from able to undertake the pilgrimage to Mecca. Often their nutritional standard is very poor, as they live off little more than maize, milk and pumpkins. The situation is often improved considerably when the herder has a wife who can go to the markets and cook (IID# 21, pers. obs.). What is of note, however, is that literacy and knowledge of English is not necessarily more wide spread among cattle owners than among herders (IID# 20, pers. obs.).

4.3.2.4.2 Remuneration structure

The majority of Fulani in the study area are working as herders who are indeed marginalised and completely dependent on their employers. The normal wage for a single herder is N500 (~NZD 5) per month; maize, clothes and shoes for the herder are provided additionally by the employer. A herder with a wife (and subsequently a family) often receives a patch of land on which he can grow crops as well as the seed supply for the first sowing, and an increased wage of N1500 per month (IID# 1,7,8,9,20,21). Herders receiving farmland from their employers are considerably better off than those receiving only sacks of maize flour as they have the possibility to sell excess produce and earn extra income to spend on other foodstuffs (IID# 21). They consequently have better nutrition through their ability to buy alternative foods. A herder that has been working for the same landowner for a long time is often allowed to farm on the employer's land wherever he pleases (IID# 18,21,3).

Additionally, the owner may give one cow (worth ~N40 000 or ~NZD 400) or bull (worth ~N55 000 or ~NZD 550) to the herder for each 6 months of labour. These additional payments, however, are optional and are given at the employer's discretion (IID# 1,7,8,9,20,21).

Nevertheless, if herders are not paid well enough or too irregularly, they will leave their employers to look for employment under a different boss, especially if they are still single and have no family to care for (IID# 9,21). Several herders have given testimony to this occurrence. It can be expected that an experienced herder will find new employment within approximately a month (IID# 20,21).

If the employer gives cattle to the herder, the herder is usually allowed to keep some cattle on the landowner's land free of charge, only when he keeps more than a negotiated number (usually 6-9), does he have to pay for the associated expenses like vaccines, medicines, salt and grazing (IID# 1,7,8,9,20,21). However, more often than not, the herders are in poor position to build up a herd, because the cost of providing for their family usually requires the herder to sell the animal as soon as it is received. If the herder does not have urgent financial family responsibilities, he may sell a male beast in order to buy a female whose calves he could sell in years to come (IID# 1,7,8,9,20,21).

This payment structure leaves the herder disempowered and almost in total dependence on the employer. Without the help of a national social security system and very limited ability to build cash reserves themselves, combined with the rural African's propensity for having big families, most herders would face grim consequences if laid off (IID# 16,9,4,13).

4.3.2.4.3 Herders' responsibilities

The herders' responsibilities include, but are not limited to, removing ticks from cattle, keeping the cattle safe from injury or theft, searching for lost cattle, making sure that the cattle drink enough water, taking the herd to the owner (or a convenient meeting point) when the owner wants to inspect the herd, taking animals to the weekly cattle market in the region, taking the cattle off and onto the plateau according to the seasonal requirements at the owner's bidding, milking cows, collecting medicinal plants for sick animals, applying immunisations (mainly against Trypanosomiasis) and other conventional medicines, weaning calves and burning the dried tussocks to stimulate new growth. These responsibilities fall on the herder additionally to the obvious, taking cattle to and from pastures, although it has to be noted that most herders let the cattle roam freely. Very often the herder takes on a more passive role, either by following the cattle around (in the reserve) or by taking them to the first pasture of the day, tending to the farm during the day, taking the cattle to a watering hole at noon and taking the herd back again to the compound (on the property) in the evening. If the cattle are losing too much weight, however, or are sleeping too much instead of grazing, the herder will drive the herd over the pasture as this is reported to stimulate their grass intake (IID# 11,12,3,20,21).

Apart from tick removal, watching over cattle and keeping them safe, the workload of the herder can be reduced considerably if he is adept at training his cattle. If the herd is well trained they will graze, drink water and return to the herder's hut on their own accord while untrained cattle will lie down and sleep or wander off as soon as they have eaten their fill. If the herd is becoming too big for one herder to handle, the herd is split and a new herder employed (IID# 1,3,11,12,13).

The limitations to individual herd size are usually set by the experience of the herder, the workload per animal (principally tick removal), the access to rivers and salt licks. An inexperienced herder usually starts off with 30 head of cattle, while experienced herders in the study area looked after as many as 80 head of cattle (IID# 1,3,20,21,22,24,R, pers. obs.). A single waterhole at a medium sized river limits the herd size to about 30 animals. If the herd consists of more animals, several different water holes are needed (IID# 1,3,5,6,20,21,23,24).

4.3.2.4.4 Influence of the Graziers' Association Yelwa (GAY)

Interviews reported that most of the more influential cattle owners (those with the largest herds) in the study area are not members of GAY and hence the association has no real impact on the grazing situation in the study area (IID# 22). According to this informant only some Fulani and Mambilla that own a few head of cattle are members of this organisation. Also, the organisation was said to be "not very active" in managing grazing (IID# 22).

4.3.2.5 Pastoral Breeds and animal management

4.3.2.5.1 Cattle breeds and their characteristics

The four types of domestic cattle encountered in the study area were all breeds of Zebu (*Bos primigenius indicus* or short: *Bos indicus*). The characteristics of the Zebu on the Mambilla Plateau closely resemble those of their common ancestor, the Indian sub-species of the extinct aurochs *Bos primigenius*. They all have a fatty hump on their shoulders, drooping ears and a large dewlap. Hump and horn size as well as stature and colouring differ between Zebu varieties (Table 4-4). Overall, interviewees discriminated between four different local breeds: Mbororoji, Akuji, Gudali and Butankeji, with the first three being the most widespread.

The cattle which are judged fit to go on seasonal migration are usually of the Akuji breed or smaller Mbororoji. The bigger bodied Gudali Zebu or Gudali crossbreeds are said to get sick from the long walk. Furthermore the Gudali cattle are said to have a lesser resistance to diseases that spread in the lowlands at the start of the rainy season. The herders interviewed also said that if Gudali females migrate too far, their calving is delayed (IID# 20,21,22,11,1,3,R).

Table 4-4: Summary of cattle breeds in the study region and their characteristics (pers. obs., Blench 1999; Boutrais 2007)

Breed	**Mbororoji**	**Akuji**	**Gudali**	**Butankeji**
Other names	• Rahaji, Bodeji, Wodaabe, Red Fulani	• Bunaji, Daneji, Yakanaji, White Fulani	• Bokoloji, Adamawa Gudali	
Physical Attributes	• Tall • Reddish-brown coat • Long thick horns	• White or black coat • Medium-sized horns • Slim	• Large stocky body • White and brown coat • Shorter horns • Big, pendulous hump	• Physically largest breed encountered in the study area • Long thick horns • Shorter stocky body
Grazing	• Very selective feeders • Reliant on good nutrition • Non-browsing	• Relatively unselective feeders • Able to tolerate limited feed availability during dry season	• Thrive on poor pastures with largely dry matter as forage • Browse	No Data
Management characteristics	• Do not resist humidity related diseases well • Able to migrate long distances	• Resist diseases well • Able to migrate long distances	• Do not resist diseases well • Not able to migrate long distances	No Data
Other	• Considered extremely prestigious • Show favoured physical characteristics and temperament • Suffers great weight loss during dry season	• Most numerous breed in Nigeria • Mostly held by latecomers to the plateau • Show favoured physical characteristics and temperament	• Physical characteristics and temperament not desired • Calve later and at greater intervals • Do not suffer as much weight loss	No Data

The most prestigious cattle species in the study area are the large red Mbororoji Zebu (Figure 4-2). The white, smaller and slimmer Akuji Zebu (Figure 4-3, Figure 4-4) are also very popular. According to interviews with the Fulani, Mbororoji need a smaller amount of fodder than Akuji, contrary to their difference in body size. Observations throughout the study period also gave the impression that cattle of the Akuji breed graze longer hours than their Mbororoji counterparts, which during the day are often seen lying around, resting or chewing cud (IID# 20,21,22,11,1,3,R).

In contrast to Gudali cattle (Figure 4-5, Figure 4-6), Akuji and Mbororoji are roamers that are able to walk long distances but also need a large grazing area (Table 4-4). Gudali cattle are able to feed on browse and the dried grasses of the dry season. They are also better at handling poor nutrition and hence do not lose as much weight during the dry season as the other breeds (Blench 1999; Boutrais 2007). However, they are unsuitable for a nomadic or transhumant pastoral lifestyle as they cannot walk long distances and are specialised on annual and perennial grasses of high altitude grasslands. Mbororoji cattle are said to be the most discriminating feeders among the Zebu breeds. They refuse to feed on browse and difficulties are experienced when trying to make them eat “new fodders”. The Mbororoji are also more susceptible to wet-season related diseases than Akuji cattle (Blench 1999; Boutrais 2007) which explains why cattle of this breed are usually leaving the plateau later and returning earlier than cattle of the Akuji breed (IID# 20,21,22,11,1,3,R).

Figure 4-2: Red Mbororoji cattle

Figure 4-3: Black and white Akuji cattle

Figure 4-4: White Akuji cattle

Figure 4-5: Red Gudali cattle with white markings

Figure 4-6: White Gudali cattle with red markings

4.3.2.5.2 Preference of breed and difficulties of nomenclature

Different Fulani clans traditionally owned different breeds. The Butankoen own Butankeji cattle, the Daneji clan has its name from its traditionally white cattle (danejum - white), Mbawankoen had mostly brown cattle and Daurankoen were known to own mostly white cattle or Sokoto Gudali. Members of all of these clans can be found in the study area (Table 5-2).

The type of cattle that were inherited from his ancestors often decides which breed an individual owner prefers. On the other hand, often one breed is preferred out of tradition, but animals of a different breed are purchased to supplement the herd. This is usually done to diversify the herd (IID# 20) or to crossbreed in order to give the herd new characteristics that are seen as better adapted to changed conditions. If an animal of a different breed is introduced the Fulani often keep crossbreeding, keeping the introduced characteristic in the gene pool of the herd while trying to retain the look of their traditional breed as much as possible (Boutrais 2007).

Boutrais (2007) reports of the British efforts to settle the Fulani by promoting a change to the Gudali cattle breed which is much more suited to a sedentary lifestyle. Although the Gudali breed is not as desirable to many Fulani of the plateau who prefer the more traditional breeds with their preferred physical characteristics, many Fulani have switched to crossbreeds between Gudali and Mbororoji or Gudali and Akuji respectively (Blench 1994; Blench 1999, pers. obs., IID# 1,20,21,R; Boutrais 2007). Boutrais (2007) refers to Mbororoji x Gudali crossbreeds as *bakalleeji*. It is hard to quantify how many cattle of each certain breed are owned by each Fulani cattle owner through interviews, because the breed of a calf is sometimes given as the breed of the bull even if the cow was of a different breed. This means that even if all the cattle of a herd were crossbreeds between Gudali and Mbororoji, where the bull has been Mbororoji some herders would still state he has no Gudali cattle in his herd (IID# 21,3). For others, Gudali just describes the fur characteristic of a calf having multiple colours. Confusing local nomenclature of breeds has also been reported by Blench (1999). A rarer breed in the area is the big Butankeji cattle that are both considerably taller and heavier bodied than the other breeds. They are said to give more milk and fetch a better price at markets due to their greater weight and size (IID# 22,23,24). All cattle kept in the study area are used for multiple purposes: as an investment, as status symbol, for meat supply and for supply with milk and milk products.

4.3.2.5.3 Calving

The cattle on the plateau get their first calf at the age of 2.5 - 3 years, although this can be delayed by 1 – 1.5 years if the cow has to migrate far during the dry season. Depending on breed, health, nutrition and exertion, cows usually calve every 1 – 2 years (IID# 1,3,20,R). Generally, cattle of the Gudali breed calve later (~3 years) and at greater intervals (2 years) than the other breeds (Boutrais 2007).

4.3.2.5.4 Economic considerations of cattle rearing

Within a herd, usually an estimated 95% of animals are female. This ratio establishes from the animal management strategy of retaining females and selling males. One big quality bull is usually kept for breeding while some smaller ones that will not challenge the lead bull are also kept in the herd (IID# 3,14,21,24,R,).

The number of cattle regularly sold by the owner to meet living expenses is difficult to predict but one interviewee estimated it to be around one per month (IID# 20). However, this varies with the number of dependants the owner has. For example, a man with only one wife and only two small children may only need to sell around one beast every 2-3 months (IID#20). More cattle have to be sold (or slaughtered) if there is a celebration and the cattle owner provides a feast or if there are other immediate needs for which he requires cash. If only a small amount of money is required, a calf or small beast is sold (IID# 5,20,21). Generally the sale amount is matched to the expected immediate expense, and this appears to be without much future planning. Other reasons for selling a particular animal can be very diverse, from personal dislikes such as being the wrong colour and local superstitions to comprehensible reasoning such as selling a cow whose mother calved late, which may be a hereditary characteristic (IID# 20). This, however, only applies to Fulani families that manage their herds for subsistence and do not run a large business, selling cattle to international markets.

Cows are not kept until they stop calving. Rather cows are usually sold or slaughtered when they start loosing teeth, which is usually around 15 - 20 years of age (IID# 20,21).

The environment on the Mambilla Plateau is generally very healthy for cattle, notably due to the absence of the Tsetse fly (Bawden 1966). Therefore their upkeep is not tied to any major costs. The only regular medicines needed are immunisations against black quarter (Fulfulde: *labba*) (~30 Nigerian Naira (NGN) or 0.28 New Zealand Dollars (NZD) / head) and against Trypanosomiases (~NGN 50 or NZD 0.46 / head) for those migrating to the lowlands in the dry season. Also a cattle tax of NGN 50 or NZD 0.46 per head has to be paid each year to the local government, which in this study is the Sardauna Local Government in Gembu (IID# 20,R). During colonial times the authorities received the greatest proportion of their revenue from this cattle-tax (Fulfulde: *jangali*) and therefore favoured the pastoralists in every way (Blench & Dendo 1984). Today the local government in Gembu still receives a significant part of its revenue from cattle-tax (IID# 26), meaning it is in the local government’s interest to see cattle numbers increasing.

4.3.2.5.5 Fulani reliance on cattle rearing

The Fulani cattle owners and herders raise cattle as their main source of income, although they may also own goats or sheep as an additional meat supply. Unlike in many other developing countries, products such as milk or wool are not taken from these animals, although the hide may be used or sold after slaughter (pers. obs.). Cow’s milk is the only milk consumed and may be processed into other products including yoghurt. The milking is usually done by women, children or herders (if single and then only for their own use), while pasteurising the milk and yoghurt making is the domain of women only. Clothes are either bought from shops selling western second hand clothes, made from cotton fabric brought to the plateau from other areas in Nigeria, China or Malaysia or are knitted using synthetic fibres bought away from the plateau (p.o).

4.3.2.6 Seasonal migration as an answer to overgrazing

When asked about their grazing practices, all herders complained about the poor quality forage on the plateau during the dry season. They say that when the wind of the dry season touches the grass, the tussock starts to die (IID# 20,21,22,23). In fact, the beginning of the dry season is marked by the arrival of the Harmattan, a wind blowing south from the Sahara, bringing dust and dry air (pers. obs.). All herders agreed that they go elsewhere when the grass gets dry and the cattle cannot find enough forage (IID# 20,R, pers. obs.).

Moving on is a common theme among the Fulani when faced with diminished feed resources for their cattle. Due to the characteristics of their breeds, Akuji and to a limited extent the Mbororoji cattle can stay in the lowlands for a significant portion of the year and thus reduce grazing pressure on the plateau. A management strategy, going hand in hand with seasonal migration is splitting the herds according to the different breeds' ability to cope with long walks and poor nutrition. This is one of the main reasons why cattle owners keep a mix of cattle (breeds, ages, sizes, genders) in each of their herds. For transhumance, members of a family often split and re-organize their herds to create new herds in which all animals are either able or unable to migrate (IID# 1,3,5,14,20,21,23,24,R).

The respondents did not seem overly concerned with the longer term sustainability of the pastures. All management strategies were always centred on the immediate health of the animals (IID# 1-16,20,21,24,R).

An interview with the herders of T provided an exception to this general attitude revealing that to prevent overgrazing on his land, the huts of the herders are shifted every 2-4 years when “the grass gets too short” (IID# 14) and to prevent livestock disease build-up (Omotayo 2003). This strategy seems to make some sense, as the land around a herders hut is the most intensively grazed and trampled as cattle will always come back to the hut at night and are able to graze in the vicinity of the hut from evening to morning. However, this management regime is also not without its problems; by shifting the huts repeatedly, a pattern of severely compacted soil is left behind. The grass sward composition changes from *Sporobolus* to Kikuyu grass or is removed completely and replaced by exposed soil which is subject to erosion. Whether or not this strategy is sustainable to manage overgrazing in the vicinity of huts depends on the time the degraded area needs to regenerate, on the severity and speed of erosion and on how much land is available for the repeated shifting of huts (Omotayo 2003). Unfortunately, as this information was collected at the very end of the field study, there was not time to study the successional change around the sites of abandoned huts.

It has been shown that both, herders and cattle owners are aware of the widespread problem of overgrazing and subsequent decline of pasture quality. The main focus however, is not the state of the environment per-se, but the fear that their cattle will suffer if degradation continues. Nevertheless, the desire for an ever increasing herd size demands that at any given time the pastures are grazed to their limits. During the wet season the majority of a cattle owner's herd will find enough forage on the land holdings on the plateau. While the wet season offers higher grass productivity, the pastures of most land owners are grazed above the estimated carrying capacity. In the dry season the biomass productivity is so low, that the majority of the herd has to be sent elsewhere, usually lowland areas where the cattle owner holds grazing rights. During this time the pastures are burnt and grazed at a lower intensity, but likely still above carrying capacity. The seasonal migration off the plateau of most of the herd can therefore not be seen as a management tool for maintaining pasture productivity.

Interestingly, although the Fulani of the Mambilla Plateau have been sedentary for some time now, the strategies to counter this demise are still mostly those of a nomadic people: Splitting herds and moving the designated grazing areas of herders while still owning an ever increasing total number of animals are management practices that may work well for a nomadic lifestyle, however, this cannot be sustained if the pasture acreage is limited, as it is on the Mambilla Plateau.

Traditionally, a Fulani cattle owner's social status and prestige rises and falls with the size of his herd (Riesman 1977). The comparison of individuals is made on the basis of the number and type of animals they possess which gives rise to the requirement that the herd be as extensive as possible. This in turn is a significant determining factor in deciding patterns of transhumance and herding strategy (Blench & Dendo 1984). The abovementioned cultural factors provide very plausible explanations why de-stocking and managing the herd in numbers that are sustainable in the long run (i.e. to prevent overgrazing) was not considered to be an option for any of the Fulani cattle owners interviewed (IID# 20,24,R).

The widespread tendency among cattle owners to strive for short term gain to the detriment of long term sustained prosperity has been blamed for overstocking and overgrazing pastures (IID# 20). This has previously been correlated with the general trend in the area since the 1970s and 1980s of Fulani cattle owners turning away from subsistence cattle rearing and meat production for a regional market towards meat production for a larger national and international market (Frantz 1981; Hurault 1998). The method usually employed to engage these bigger markets involves live cattle being loaded on trucks and transported to bigger cities that have an abattoir where the animals can be slaughtered. There is no such facility on the Mambilla Plateau (Chapman 2008, pers. comm.). Reasons other than market influences potentially explaining the focus of Fulani land owners on short term gain include the increasing conflict between farmers and pastoralists on the plateau and the associated insecurity of land tenure in the future (Dunn 1994). One interviewee suggested the general lack of education in Mbororo households to be responsible for the lack of long term planning and sensible investment in anything additional to cattle (IID#21).

On the Adamawa Plateau in neighbouring Cameroun, one of the great benefits gained from cattle rearing is that the herd substitutes a banking system, which is often absent in rural Africa. Surplus realised in good years can be stored to a degree in a larger number of animals, thus having a larger herd provides a buffer against poverty and minimises food insecurity (Green 2004; Garcia-Barrios, Speelman & Pimm 2008). Entrepreneurs and businessmen of sub-Saharan Africa fear the collapse of instable currencies or banking systems, hence they store their wealth in commodities rather than banks (Green 2004). For this purpose, owning livestock on the Mambilla or Adamawa plateau seems ideal, as the climate is stable and conducive to good health of the herd, making a sudden collapse unlikely. Furthermore, 'interest' can be accrued through progeny of animals.

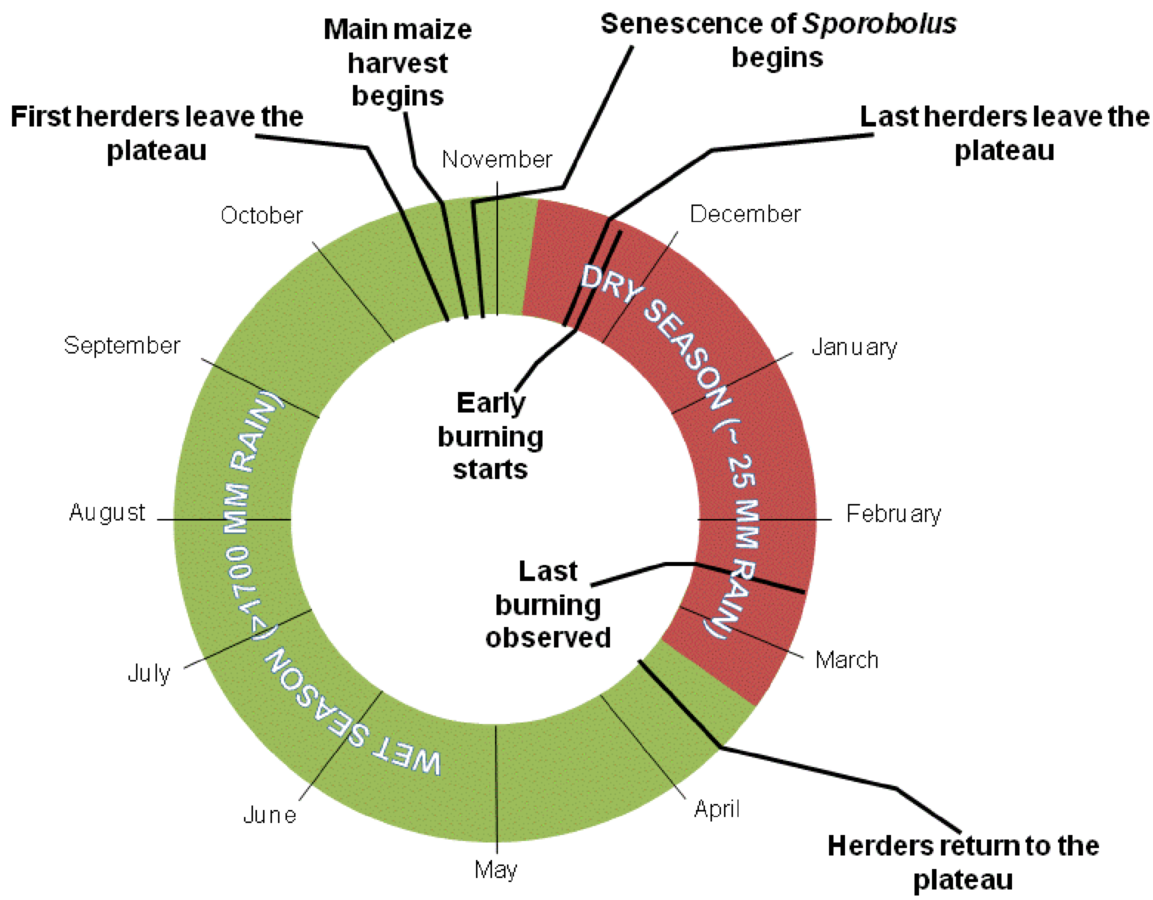


Figure 4-7: Annual cycle of dry and wet season activities around Ngel Nyaki

4.3.2.7 Grazed species

4.3.2.7.1 Grasses

The main grazed species that were able to be identified in the study area were the long *Hyparrhenia* grasses, and shorter *Sporobolus* tussocks, interspersed with *Pennisetum* species and unidentified mixed herbage. In addition, larger extents of the very trampling resistant, lawn forming Kikuyu grass (*Pennisetum clandestinum*) can be found around herder's huts.

Herders pointed out different grass species and explained some grasses were good for the cattle hide while others were good for their bones, but the main distinction made was between the dried tussock and grass that "gives the cattle power," which included all grass species that remain green in the dry season. There also seem to be differences in the importance of different grass species at different times of the year. One very important species for cattle in the wet season is very vulnerable to cattle trampling and hence it is lost quickly after all the herds have returned to the plateau (IID# 1,3,22,R). *Sporobolus* tussock grass, the major fodder species on the plateau in the wet season, loses its value during the dry season as it goes into senescence, while rare nutritious greens increase in importance (IID# 1,3,6,R).

In contrast to several publications (Bawden 1966; Frantz 1981; Hurault 1998; Chapman, Olson & Trumm 2004) the interviewed Fulani had not observed a change in grass species composition over the years, specifically suggesting that important grasses for cattle nutrition have become neither more nor less abundant through time (IID# 1,3,20,R). A simple explanation for this could be that the interviewed Fulani have arrived after a major ecological shift from *Hyparrhenia* to *Sporobolus* had already occurred or that they are simply unaware of any changes that are occurring.

4.3.2.7.2 Browse

From the evidence gathered from interviews and observations, browse appears to be of minor importance for cattle in this area. Herders stated that sometimes cattle would eat young bracken and other types of soft leaved vegetation found at the edges of riverside forests (IID# 1,3,9). Cattle browsing has only been observed very sporadically throughout the duration of the field study even when the grass was dry and plenty of potential browse available. In interviews, the Fulani mostly mention grass in relation to its quality and availability. Forest edge vegetation often comprises a thicket of *Aframomum* vegetation, brambles, woody shrubs and long grasses. On many Fulani properties this type of edge vegetation is cut and burnt by the herders towards the end of the dry season (pers. obs.).

Some herders raise a few goats or sheep to supplement their diet with meat or to sell at the market for additional income. These animals are usually few in number (<15) and stay close to the herder's compound (IID# 3, pers. obs.). No native browsers have been observed during this field study, although the presence of duikers

(Cephalophinae) has been reported (IID# 22,23). In the past, buffalo (*Syncerus caffer*) were reportedly seen along the wetlands of Mayo Jigawal, however these animals have been absent now for a number of years (IID# 22).

4.3.2.8 Watering

Drinking water was named as an important activity for cattle in the dry season to stay healthy and "have power". Conversations about the herds' needs, however, always led to a discussion of pasture and the quality and abundance of forage and never about water access. From this, it can be deducted that cattle hydration, while an essential activity, is not considered to be a limiting factor. When asked about the importance of streams in the reserve for cattle, most interviewees emphasised the importance of the grass in the reserve for their herd. Nevertheless, all herders make sure their herd has access to watering holes two to three times a day during the dry season and some herders grazing the reserve also take their herd to watering holes within the reserve (IID# 5,8,9,U). Others enter the reserve for grazing and take their herd back to a stream on their employer's property for watering (IID# 10,11,16). Although access to water was never stressed as an important factor in any of the interviews, all herders grazing within the reserve also water their herds there at least some of the time (IID# 5,6,7,9,16).

4.3.2.9 The Fulani and the Reserve

4.3.2.9.1 Herders

The interviews conducted contained valuable information about the interaction between herders and the reserve.

4.3.2.9.1.1 Reasons behind grazing the reserve

The main reason given by the herders for grazing the reserve was that grass within the reserve stays fresh for longer into the dry season. The northern part of the reserve has distinctly more tree vegetation than the Fulani properties outside. The whole transition from grassland to savannah to forest can be observed there. When asked why they think the grass is fresher there, the herders answered "it is because of the trees that the grass is fresher" (IID# 5,24). The approximate range for each herder within the reserve as well as the locations of the temporary huts is given in the following chapter on land use.

After herders left their grazing areas in the reserve, they were usually left vacated until the end of the dry season (pers. obs.). Cattle observed in the reserve were virtually always accompanied by a herder (pers. obs.).

4.3.2.9.1.2 Other activities within the reserve

Many herders have temporary huts within the reserve that are occupied for a portion of the year. Often trees around these huts are ringbarked or cut down and used for firewood and fencing (pers. obs.). Sometimes a few fruit trees, pumpkins, beans or a few stalks of maize are planted around these temporary huts, although no great investments are made towards farming and the planting of eucalypts for fuel wood and timber is absent within the reserve (pers. obs.).

4.3.2.9.1.3 Boundaries

Of the herders interviewed some claimed not to know the boundaries of the reserve while others were able to identify the boundary very easily. Within the reserve, every herder has his own grazing area where he takes his cattle, and the herders are careful not to venture into the grazing area of a neighbouring herder to avoid serious conflict between the two cattle owners. It has been observed that this general rule only applies if the area is currently grazed, not if the neighbouring herder has gone on transhumance. The area within the reserve appears to be almost as compartmentalised as the land outside the reserve (IID# 5,6,7,9,15).

4.3.2.9.1.4 Wet and dry season grazing strategies

The predominant transhumance destination among herders was Dujere although not all of them went on seasonal migration that year. Only one respondent admitted to grazing the reserve in the wet season while another interviewee said that he was grazing the reserve only between seasons. The rest of the herders stated that they grazed the reserve only in the dry season. However, cattle tracks found throughout the northern part of the reserve are often deep grooves (up to 1m) with hardened hoof-prints on the bottom. This would indicate that considerable cattle traffic is occurring along these tracks during a time when the ground is soft and rich in moisture and not hardened and dry as it is the case during the dry season. Hence, the herders' statements about this matter may not be entirely credible and future research into the herders' seasonal use of the reserve is required.

If grazing in the reserve is occurring both in the dry and wet season this would confirm the overall impression that the stocking rates on the owned properties is unsustainably high, and expansion is sought to relieve the overgrazed pastures.

4.3.2.9.2 Land-/ Cattle owners

All except one of the interviewed landowners expressed their dislike of the ongoing conservation efforts in the area. As the landowners knew I was associated with the NMFP and hence saw me as associated with the whole conservation project, their attitudes towards me can be partly interpreted in the light of their attitude towards the reserve.

One landowner (G) declined my request for an interview with the words, "He (myself) is not welcome on my property, if he shows up at my compound or talks to my herders I will call the police." Another land owner (T) was friendly when I met him at a market and agreed to an interview, but when I sought him out at his compound at the pre-arranged day and time he had left early and was not available after all. This happened twice, which I took to be a sign of refusal. In the short conversation at the market, this land owner stated, "They have taken away half my land to make the reserve. They used to call me Alhadji T of Ngel Nyaki. Do they want to take away even more land now?" Nevertheless, he gave me permission to talk to his herders at my leisure.

Landowner U, who owns land in the study area, although not adjacent to the reserve, mentioned that he owns cattle that are "drinking water" in the reserve and asked if this was a problem. It turned out he employs two herders who live permanently in the reserve (at least) during the dry season. These herds graze and water there and the rangeland is burnt, in a similar manner to the rest of the study area.

Landowner E, who has a herder permanently living in the reserve during the dry season, was willing to be interviewed and said he does not fell any trees around the herder's hut, because it is prohibited by the government. He also mentioned that he filed a complaint against being excluded from the reserve with the court in Gembu and is waiting for the outcome.

Another landowner, (R) whose cattle are not grazing the reserve, took the request for an interview as an opportunity to practice his English. He was the only person among the interviewed Fulani herders and landowners who had any knowledge of English and was quite proud to have some knowledge of the language. He told me he respects the boundaries of the reserve and he does not burn or graze right up to the trees and does not cut down trees. He also mentioned his annoyance that in court cases he is named (by other land owners) as one of the cattle owners that graze the reserve when in fact he does not. He said that they (the other land owners) want to make it look like everyone is grazing the reserve, although that is untrue.

These responses mirror quite aptly the range of attitudes towards the reserve among landowners. These attitudes ranged from hostile (G), anger and avoidance (T) through to downplaying of their activity in the reserve (U), taking legal action against exclusion (E) and finally acceptance (R).

All land owners that I talked to, however, were at a loss as to the benefits of the existence of a reserve when nobody is allowed to utilise its bounty. Typical comments that illustrate this include the following:

"What good is the reserve if there is no grazing?" (U)

"I am curious. What is the reserve good for? Why should nobody go there?" (R).

"I have always been taking my cattle here, why should I not go here anymore?" (E)

These questions show clearly a lack of community involvement in reserve establishment and management and that the NCF's enlightenment strategy has failed to reach the cattle owners.

4.3.2.10 Burning

Two to three weeks into the dry season, as the tussock grasses begin to dry, the Fulani herders start to burn the dried patches (pers. obs.). Before they are allowed to burn the land they have to get permission from their employer, the landowner. The landowner in turn has to buy a burning permit from the local government authority in Gembu before he can give permission. The early fires are started on the driest parts of the property, usually until half of the property is burnt. This ensures that patches of green, nutritious, grass regrowth are available by the time the majority of grass across the property is senescent, barely palatable and low in nutrients. A good knowledge of the cattle's needs is required in order to burn the correct extent of pasture. Burning too small an extent would result in too little regrowth resulting in poor cattle nutrition, while burning too large an extent would leave too little overall biomass on the pasture to sustain the herd (IID# 3,5,9,20,21,22,23).

In early burns, the extent of the fire is confined to the driest patch of grass. As the vegetation still contains a relatively high moisture content, the fires go out of their own accord when the boundary of a dried patch is reached. This creates a mosaic of burnt patches that serve as fire barriers during later burns, because the recently burnt patches (1) have fresh, fire resistant regrowth and (2) do not have enough biomass accumulated for fires to be able to spread. The herders also control the direction of burns by setting fires when the wind is blowing from the desired direction at the right strength. Herders additionally use the topography in controlling burns. If a whole hillside is to be burned, the fire is started at the very bottom of the slope, but if only half of it is to be burned, fires are started midway up. The fires typically burn downhill only to a very limited extent, while most of the pasture uphill will be consumed (pers. obs.). It is their goal that by the end of each dry season, the whole property has been burnt. Unburnt patches are only left by mistake (IID# 20, 21,23,24).

Hotter fires during the middle of the dry season usually serve the purpose of removing woody vegetation (bracken and trees) as well as weeds and ticks, however, there is no fire management regime that seeks to favour a certain species of grass (IID# 20). At this time, back-burns are undertaken around farms and compounds to protect them from uncontrollable late fires. There is very little tussock regrowth coming from these late fires (pers. obs.). This is probably due to the very limited soil moisture left in the ground, preventing new grass from germinating. Late fires, laid shortly before the return of the rains, also serve pasture improvement purposes by removing undesired woody growth and by preparing the grassland for rapid regrowth (see chapter 6). Rapid regrowth is mostly related to soil moisture content, although late burning may increase productivity further due to a fertilising effect of the ashes. However, the ashes from grassfires are usually only rich in phosphorous and calcium, while most of the carbon and nitrogen locked up in dried grass has been released to the atmosphere as gaseous compounds (CO, CO_2, N_2O, NO_X) (Kauffman *et al.* 1993; Cook 1994). The deposited ash is also prone to erosion by wind and water (Kauffman *et al.* 1993; Van de Vijver, Poot & Prins 1999) and the ferocity of the wet season rains, and the compacted nature of pasture soils quite likely results in most of the ashes being swept away, rather than being fixed in the soil with the infiltrating water (Savadogo, Sawadogo & Tiveau 2007). In addition, vaporised organic matter can move downward through the soil horizon and form a hard, water-repellent pan that inhibits water infiltration. After a first nutritive boost through nitrogen released by fire and deposited on the surface, a long term nitrogen deficiency is often reported to set in (Dennis 1988; Van de Vijver, Poot & Prins 1999). Therefore, the annual grassfires in the study region are very likely to reduce soil nutrient status over the long term.

The burnt stubble is frequently eaten by cattle and could potentially be important in cattle nutrition. Fulani have expressed the view that cattle like to eat this stubble as it is “like salt”, “sharpens their tongues” and “gives them power” (IID# 1,3,5,20,21,22,23,24).

In 2008, the burning of pastures started on the 12th of November, approximately two weeks after the last rainfall. It seemed like only a very small proportion of each property was subject to this early burning. The fires were at their widest spread across the grasslands around the 20th of November and were also observed within the reserve. Within the reserve almost the whole grassy area was burned around this time. On Fulani properties outside the reserve approximately up to a quarter of each property was burned between mid November and mid December. Fewer fires of lesser extent were spotted regularly inside and outside the reserve throughout the rest of the dry season (pers. obs.).

4.3.2.11 Logging

Two protected forests exist within the study area, Ngel Nyaki and Kurmin Danko which together make up the protected area “Ngel Nyaki and Kurmin Danko Forest Reserve”, in which farming, extractive uses (with some exceptions) and grazing are prohibited (MacDonald 2007). However, the streamside forests on Fulani properties outside the reserve also seem to enjoy some level of protection. When herders outside the reserve were asked where they get their firewood and their building materials from, they answered that either they gather deadwood from streamside forests on their employer’s property, cut *Eucalyptus* trees (fulfulde: *jaiti*) or cut trees from the streamside forests. In the latter case they have to get the permission from their employer, who in turn has to purchase a permit from the local government authority. The price named for such a permit was N1000 (NZD 10) per tree felled (IID# 1,3,5,20). The herders agreed that if a person was found to have cut a tree without such a permit, that person would face prosecution, resulting in a hefty fine and perhaps jail time if unable to pay the fine (IID# 1,3,5,21).

Although the law protects Forest Reserves more strictly than the riverside forests, felled and ringbarked trees and large areas of burnt ground can be seen throughout most of the reserve. These signs of degradation are particularly visible in northern Ngel Nyaki Forest, along the southern edge of the continuous forest fragment in southern Ngel Nyaki and along the boundary of Ngel Nyaki with the lowlands (pers. obs.).

Streamside forest clearing is also necessary when techniques such as valley-bottom cultivation are employed. On the Mambilla Plateau agricultural fields are often located along and sometimes even in streambeds (outside the reserve) (pers. obs.). In these areas the soil holds more nutrients and higher moisture content, crucial during the drier part of the year. In addition to clearing streamside forests for farming some clearing is done to provide access to streams for cattle (inside and outside the reserve).

The only trees planted are the fast growing introduced eucalypts, which are planted next to homesteads and in stream headwaters (pers. obs.). Interviewees have observed a reduction in stream flow in response to this practice (IID# 22, Chapman 2008, pers. comm.). It has been shown that fast growing species like *Eucalyptus* demonstrate especially high water consumption during their main growth phase (Kuczera 1987; Vertessy *et al.* 1996). Most eucalypts in the study area were planted less than 30 years ago, so these plantations are still in their main growth phase and at the peak of their water consumption. This may explain the interviewees' observations. As mentioned in chapter 3, *Eucalyptus* afforestation within the study area is limited to Fulani properties, plantations within Yelwa Township and state owned plantations.

4.4 Conclusions

Although basic, the informal semi-directed interviews yielded a wealth of information that considerably adds to the knowledge base of the human-environment interactions in Ngel Nyaki Forest Reserve and its immediate surrounding. The main insights pertaining to the aims of this section can be summarised thus:

<u>Social structures and power dynamics:</u>

- The Fulani in the study area belong to two different socio-economic classes, namely the disempowered, marginalised herders and the relatively wealthy and powerful land/ cattle owners
- The herders graze their cattle in the reserve at their employers bidding.
- The regular responsibilities of a herder have been outlined as guarding the cattle against theft or injury, ensure they are drinking enough (esp. dry season), limiting their access to the rare nutritious forage (dry season), take cattle to the market, guide them when on transhumance, remove of ticks
- The current land tenure system has been relatively stable in the past, but a change in this system is feared by many Fulani.

<u>Animal and pasture management</u>

- There is an awareness of the effects of overgrazing by herders and land/cattle owners. However, the strategies adopted to cope with this problem are still those of a traditional nomadic people and are inadequate to address the problem in their modern position as semi-settled pastoralists.
- The Fulani perceive the Mambilla plateau as a healthy location for cattle rearing and hence, as a place requiring little monetary input.
- The interviews and observations have revealed that although the main income for Fulani cattle owning families comes from the sale of animals, they grow a significant amount of foodstuffs themselves. The proportional reliance on home-grown foodstuffs is higher for herders than for cattle owners.
- It has been shown that Fulani are very particular when it comes to their preferred breed of cattle. On the other hand, they do often crossbreed to give their herd qualities that are better suited to local environmental conditions while taking care to ensure that the animals retain the appearance and behavioural qualities of the ideal breed.
- The demands of the local herds for water and fodder have been outlined.

Interaction with the reserve

- Through interviewing herders, I showed the main reason for using the reserve in the dry season is the decreasing fresh forage availability on the Fulani properties during this time.
- Pasture management practices, including burning and tree cutting to create stream access for cattle, are carried out within the reserve in the same manner as outside the reserve.
- The attitudes of land owners towards the conservation efforts have been shown as very negative. At best, they did not understand the benefits of forest preservation.
- It became apparent, that water availability is in most cases not a critical driver for grazing within the reserve. However, this may change in the future as logging and Eucalyptus planting in the riverine forests on the Fulani properties may lead to changes of the area's water yield.
- Clues have been provided that suggest the stocking rate on the owned properties is unsustainably high and expansion is sought to relieve the overgrazed pastures.
- I found indications that, while the NCF's 'enlightenment' strategy may have reached the indigenous population (that tend to send more of their children to school) to some degree, the cattle herders and land owners are quite oblivious to the reasons for the reserve's existence.

Chapter 5: Exploring land-use around Ngel Nyaki Forest Reserve

5.1 Introduction

The objective of this research was to understand land use and the local drivers for land use change around Ngel Nyaki Forest Reserve. Remotely sensed images, observational and interview data were combined to create current GIS land use layers. From these, possible implications for land cover and ecosystem functioning are explored.

5.1.1 Land use change and effects on natural ecosystems

Land use change is a major driver of land cover change, which in turn affects ecosystem services and functioning (Vitousek 1997). Globally, there are two general trends of land use change. The first is pastoral and agricultural expansion and intensification leading to a net loss of natural ecosystems, as is occurring around Ngel Nyaki Forest Reserve. The second trend is the abandonment of unproductive or marginal lands and subsequent natural regeneration of natural ecosystems (Izquierdo 2009). Within the study area, abandonment of farming plots in the reserve has occurred where local farmers were evicted from the reserve in 1969. These plots have now mostly recovered (Korndoerfer 2010) where abandoned farms have not been converted to rangelands by the local pastoralists. The provision of off-farm employment, for example, in urban centres, potentially may also persuade people to abandon marginal lands voluntarily and allow regeneration to occur.

Urbanisation can either positively or negatively affect natural ecosystem extent and quality. Urban land is usually characterised by overwhelming landscape modification that leaves little space for natural ecosystem functioning. On the other hand, rural-urban migration often decreases population densities in rural areas, potentially allowing natural ecosystem recovery (Izquierdo 2009). Urban centres offer off-farm employment, alternative livelihoods and provide access to larger markets creating attractive alternatives to subsistence farming on marginal land (Rudel *et al.* 2005). Izquierdo and Grau (2009) describe a distinct rural-urban migration pattern in the sub-tropical highlands of Argentina, resulting in the abandonment of marginal farmland and intensification of agriculture on flat areas comprising good soils suitable for modern intensive agriculture. This reduction in population pressure on areas of marginal farmland resulted in their reforestation (Izquierdo and Grau 2009).

In the area around Ngel Nyaki, the township of Yelwa has managed to concentrate the majority of the population in one location with farmland tightly surrounding the village, instead of scattered slash and burn plots in the forest. However, the Fulani cattle owners and cattle herders usually live close to their cattle, in scattered hamlets throughout the countryside. In this case the urbanisation and concentration of the farming population, which could lead to a forest transition is cancelled out by the extensification and intensification of cattle grazing.

5.1.2 Land use change in montane locations

The most common land use in tropical montane locations is swidden agriculture (slash-and-burn), cattle grazing and in some places cash-cropping (Kaoneka & Solberg 1994; Imbernon 1999; Fox 2005; Cayuela, Benayas & Echeverria 2006; Arredondo-Leon, Munoz-Jimenez & Garcia-Romero 2008; Lovett & Prins 2009). Some highland areas also report increasing numbers of tree plantations of fast growing tree species (Imbernon 1999; Farley 2007).

Most conversion occurring in these locations is from natural forests to agricultural fields, although Fox (2005) describes a case where most natural forest was lost to plantations of exotic tree species.

Reforestation trends are usually explained using the “forest transition theory”, which states that increases in forest cover occur when economic development leads to abandonment of agricultural land, leading to subsequent regeneration or when forest scarcity (acute or projected) prompts increases in plantation establishment. However, Farley (2007) also points out that establishing plantation forests can be a means for economic development, not only a consequence of it, as has happened on the Ecuadorian Highlands.

5.1.3 Land use change and protected areas

Land use change within protected areas and their buffer zones can affect biodiversity conservation outcomes, especially if the protected area does not cover all local ecosystems. For example, a reserve in a tropical montane region located in the northern Peruvian Andes has been reported to have great discrepancies in the conservation of different ecosystems (Kintz, Young & Crews-Meyer 2006). While the wet montane forest extent in this reserve increased, in the buffer zone 25% of the moist montane forest was lost over 14 years, mostly due to forest conversion to agricultural land. This demonstrates the effectiveness of protected areas to advert some land use changes, but at the same time points out the necessity for LULCC monitoring and subsequent protection of vulnerable habitats. Another approach called integrated landscape management, which was put forward by Cayuela *et al.* (2006) departs from traditional reserve management. Using a montane region in Chiapas, Mexico as an example, Cayuela *et al.* (2006) argue that land tenure laws are crucial in steering land use change and propose. Land tenure laws should encourage farmers to use an integrated multiple-resource approach, to increase people’s identification with the landscape and their environmental awareness. This argument resulted from research of a land tenure situation where farmers only had the right to use the land and to a certain extent the wood resource, while other resources including water, wildlife and fish, remained exclusive property of the federal government. This situation was identified as the main driver for environmental degradation in this setting.

5.1.4 Effects of grazing

If, as in many montane areas, the dominant land use is grazing of rangelands, an evaluation of grazing intensity and frequency is crucial when impacts on land cover and ecosystems are to be assessed. Other disturbances frequently associated with grazing, such as the burning of pastures, also have to be taken into account when predicting land use effects on future land cover (Kintz, Young & Crews-Meyer 2006). The stocking rate, a measure of grazing intensity[12], is critical in affecting land cover as a low stocking rate can increase tree and shrub encroachment into grasslands through succession, while high stocking rates can lead to pasture deterioration and desertification (Ramirez-Marcial 2003; Sawadogo, Tiveau & Nygaard 2005; Traoré *et al.* 2008). This holds true in regions where annual and inter-annual precipitation is not low or erratic. The latter conditions lead to vegetation growth being mainly determined by presence or absence of soil moisture rather than grazing pressure (Behnke, Scoones & Kerven 1993). Burning in association with grazing has different outcomes, depending especially on fire intensity, modified by a complex interaction of environmental variables. A simplified model suggests that very early burning can lead to shrub and tree encroachment into grasslands by removing grass cover and allowing seedlings to grow as the low temperatures of early burns do not harm many seedlings. Late burns on the other hand burn at higher temperatures, destroying established woody vegetation leading to deforestation (Afolayan 2008).

5.1.5 Land use in the study area

The land use with the largest spatial extent in the study area is cattle rearing with associated burning of pastures and rangelands. As has been described in section 2.1.3, the study site comprises a seasonally dry tropical montane area with annual rainfall of >1700mm. Precipitation is distributed very unequally between a wet and a dry season, with >95% of annual rainfall occurring during the wet season. This makes well adapted land use crucial for sustainable development. During the 5 month dry period, the vegetation experiences severe moisture stress, while year round cattle grazing and dry season burning potentially lead to deforestation and reduced vegetation cover. This and maladapted agricultural techniques may potentially lead to severe erosion during the heavy rainfalls of the wet season. Furthermore, there exists a protected area within the study site which also may be degraded by illegal grazing within the reserve boundaries.

5.2 Aims and Goals

The main focus of this section lies in (1) measuring the areas used for grazing, for cropping and those areas left as unmodified land, (2) estimating grazing intensities and stocking rates both outside and inside the reserve, (3) approximating the distribution of land holdings and (4) mapping important grazing and migration routes.

[12]The stocking rate is usually given in the literature as number of animals per land area [head/ha] or as the land area available per animal [ha/head]. Another measurement is the tropical livestock unit (TLU) per land area or land area available per TLU. One TLU corresponds to one 250 kg bovine. Animals smaller or larger, of the same or a different species can be converted to TLUs depending on their body weight as the body weight of an animal usually corresponds reasonably well to its body weight.

5.3 Material and methods

5.3.1 Software

All image processing was undertaken using the ArcGIS package, version 9.2. GPS points were downloaded from a Garmin field unit, model GPSMAP®60CSx, with the Garmin MapSource software, version 6.15.7. The same software was used to edit GPS data. GPS point tables exported from MapSource were edited with Windows XP Notepad and converted to a format compatible with the ArcGIS software package. In the ensuing steps, the GPS data were handled exclusively with the ArcGIS package.

5.3.2 Data

5.3.2.1 Satellite imagery

The land use described in this chapter relies on the same satellite imagery used for the land cover and land cover change analysis of chapter 3.

5.3.2.2 Field data

All field data were collected during one field season from October 2008 until February 2009. As no official documents about property ownership, property boundaries and reserve boundaries were available to me, the land use GIS layer set mostly consists of information gathered by observation and interviews.

GPS points were collected in the field with a Garmin GPSMAP 60CSx unit. Where appropriate, the tracking function was used to automatically collect positional data every 30m. This information was essential when marking transhumance routes and tracing the reserve boundary.

5.3.2.2.1 Study focus areas

The locations of the northern and eastern Ngel Nyaki Forest Reserve boundaries were confirmed by remnants of boundary demarcation beacons in the field, or in their absence, I was informed by local herders. The western and southern boundaries were extracted from GPS points of an earlier expedition along the whole reserve boundary made available to me by Dr. Hazel Chapman.

Property ownership was derived from interviews. Herders walked the property boundaries with me or pointed them out where visible landmarks made this possible. Fences were delineated using the mobile GPS unit while landscape features like rivers or Eucalypt plantations demarcating property boundaries were identified and digitised from satellite imagery.

5.3.2.2.2 Farms and residential

Farm boundaries were clearly visible on the QuickBird satellite image (Figure 3-1) and as farms and grasslands could not be differentiated through the spectral classification process, their perimeters were digitised directly from the image. The locations of herders' huts were recorded where possible while travelling extensively in the field. Huts situated too far off track to be marked by GPS were first located on the QuickBird satellite imagery and then digitised.

5.3.2.2.3 Transhumance

The two main dry season transhumance destinations in the area are Dujire and Mai Njebbe. GPS points were collected every 30m during a trip made to Dujire along these migration routes to provide the exact location of the path and the village.

Mai Njebbe was located too far from the field station for the route to be walked and mapped in the same fashion. Therefore, the route was mapped up to the escarpment and the further course of the path was pointed out from this elevated position by a herder. The village of Mai Njebbe was found on a topographical map from 1960 and its location was digitised. The path to Mai Njebbe was also marked on this map, so it was additionally digitised and its course updated with the aid of the QuickBird satellite image on which large parts of the migration route were visible.

5.3.2.2.4 Cattle locations

At the beginning of the field season a photograph of the northern part of Ngel Nyaki was taken from a fixed photo location in front of the NMFP field station. The locations at which cattle were spotted were marked on this picture. As the picture became populated with cattle sightings, it became apparent that there were only 11 areas inside the reserve where cattle were regularly spotted (Figure 5-1). During the first two weeks multiple observations were made every day. As soon as it was established that the best time of day to spot herds was in the mornings and evenings, observations were conducted only during these time periods. With a telescope, the northern part of the reserve was scanned for cattle and the number estimated. When the mid dry season locations of cattle sightings and herd identities stayed the same for two weeks, the number of observations per week was reduced to three due to time constraints. Additional sightings of cattle were taken during the course of other fieldwork, with the time of day being recorded in addition to the other data.

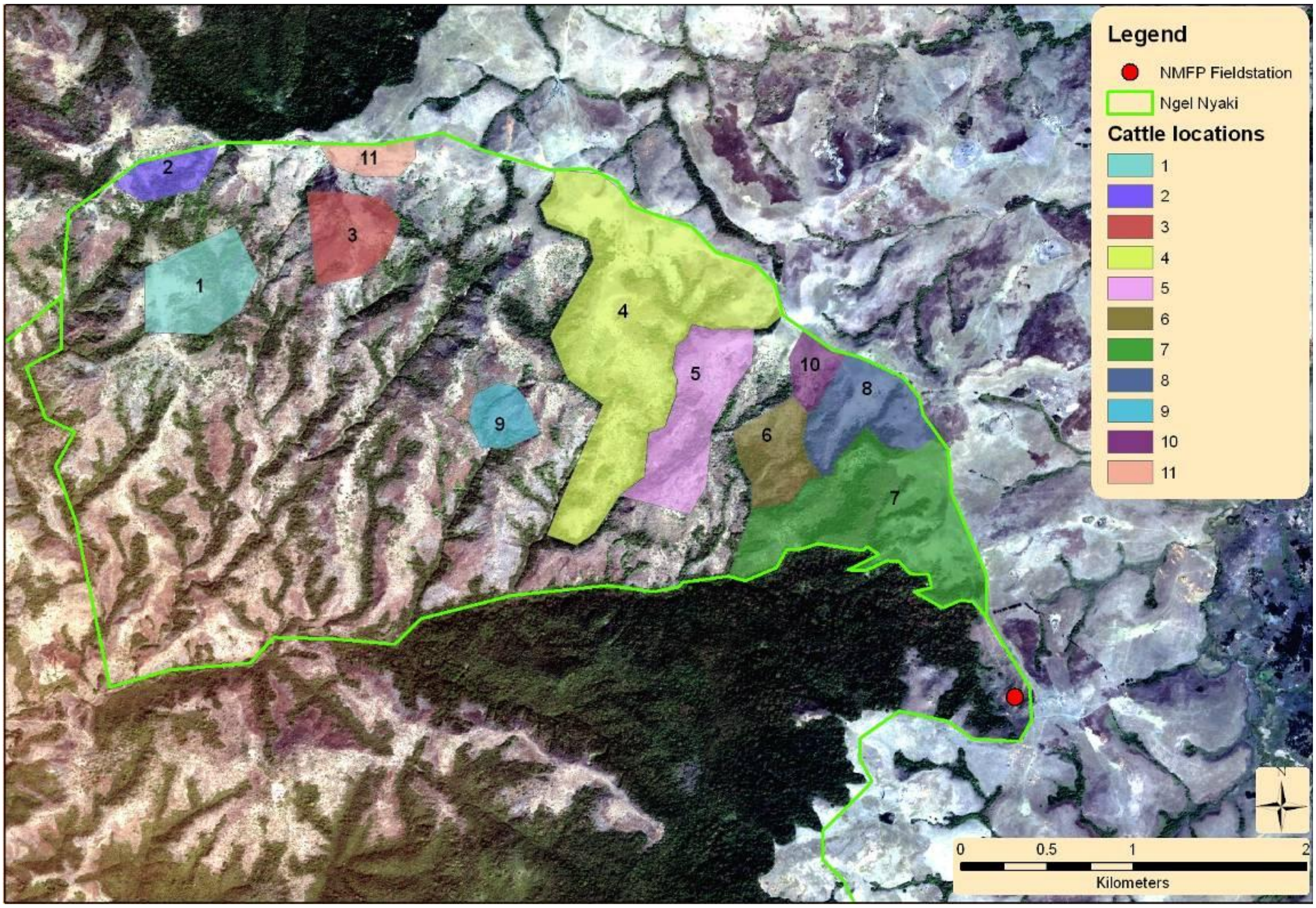


Figure 5-1: Locations of cattle sightings inside the northern part of the reserve

Cattle movements were observed throughout the day for the course of the whole field season. Additionally, cattle tracks inside the reserve were walked and marked with the mobile GPS. Tracks visible on the high resolution QuickBird imagery were digitised. The movements of the herds within the reserve were inferred through observation including cattle tracks and traces of cattle dung in addition to interviews with herders.

For interviewed herders the number of animals can be expected to be accurate. The approximate area of reserve used by these herders is also likely to be accurate as herders usually pointed out where they would go with their cattle. For non-interviewed herders, cattle tracks, confining landscape features and burn marks were used to infer approximate boundaries.

5.3.2.2.5 Land tenure and estimation of herd sizes

Land ownership was reported to me by herders encountered at different locations in and around the reserve. As local people were unfamiliar with the use of maps, the information was cross referenced by asking my field assistant who knew some of the landowners personally. In addition, conversations with 27 were used to confirm the land ownership of certain areas. GPS and satellite imagery were used in a GIS to demarcate property boundaries. The "calculate area" function in ArcGIS 9.2 was used to determine property sizes.

As demonstrated in chapter 5 the resolution of the remotely sensed imagery is good enough to distinguish individual herders' huts. The huts were counted and attributed to the landowner on whose land the hut was located.

Herd sizes of 14 interviewed herders were used to calculate an average herd size per herder, which, multiplied by the number of employed herders on a property, gave an estimation of the total number of cattle owned by each landowner. This estimation can only be used as a rough idea of herd sizes as encountered herd sizes are only representative of the dry season and uncertainty exists about the exact number of herders present in the area.

5.4 Results

5.4.1 Cattle observations in northern Ngel Nyaki

Although northern Ngel Nyaki is formally a protected area, it is widely used as rangeland. Here qualitative and quantitative data are presented to estimate grazing pressure in this area.

As mentioned in section 5.3.2.2 cattle were only seen in 11 locations within the northern part of the reserve (Figure 5-2) while a large network of cattle tracks were visible throughout the northern part of the reserve.

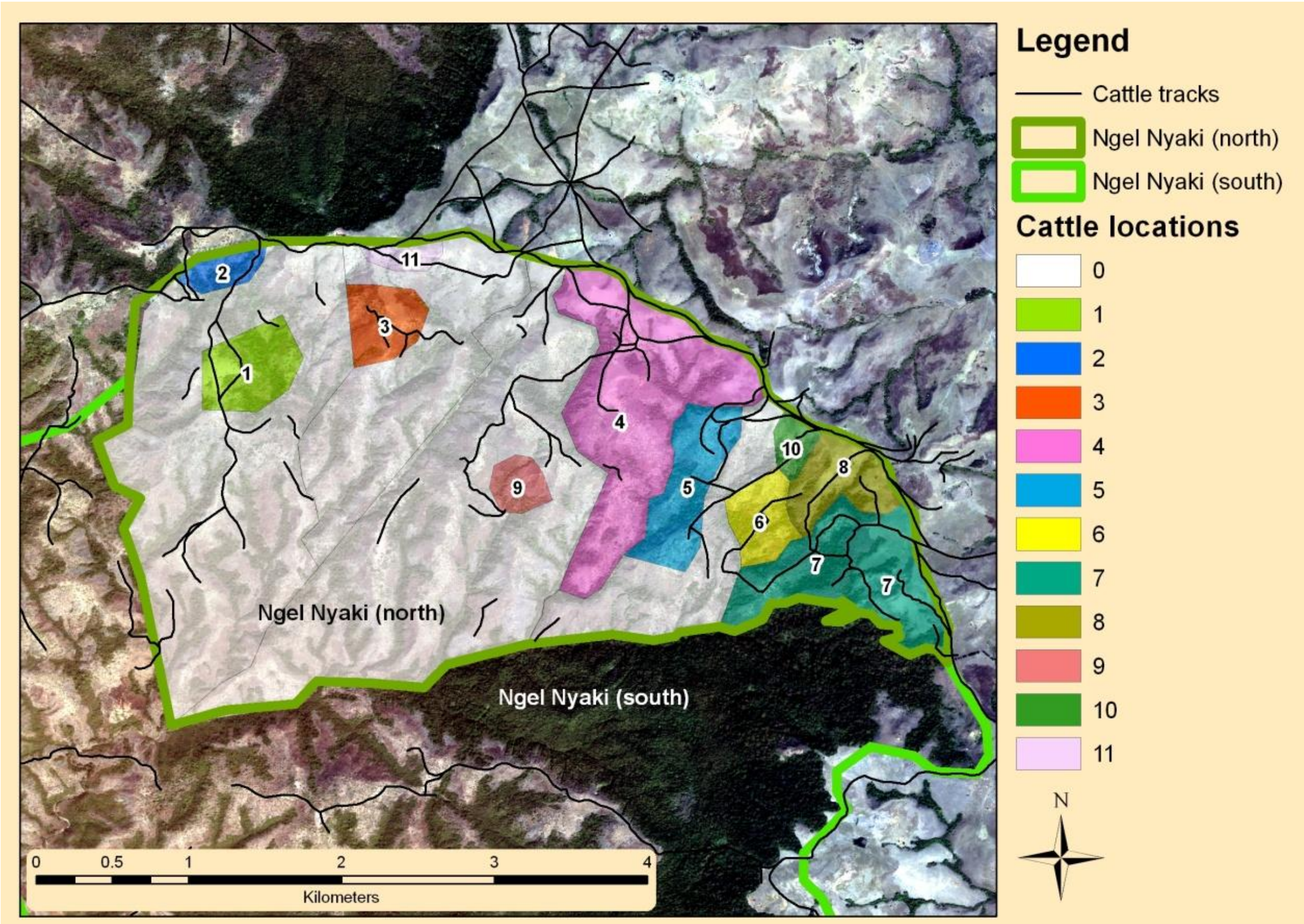


Figure 5-2: Locations of cattle sightings inside the reserve

Of the 11 locations under observation four became vacated during this particular dry season. Three were vacated at the very beginning of the dry season while the other was grazed for the first quarter of the dry season before being vacated. Most of the remaining herds grazed the reserve almost daily while the time of day they ventured into the reserve varied from herder to herder. Some herders grazed their cattle in the reserve from early morning until around noon, while others spent the whole day in the reserve and were observed going home in the late afternoon. Occasionally, herds were taken into the reserve around noon and stayed there until the evening. Location 10 was the only location that was solely grazed in the afternoon.

The number of cattle observed grazing in the reserve for at least some of the dry season came to a total of 461, while 288 stayed for the whole dry season (Table 5-1). This equates to a rough stocking rate of 39 head or 30 TLU per km^2 at the beginning of the dry season and 24 head or 18.5 TLU per km^2 after the vacation of four plots.

Table 5-1: Results of cattle observations in northern Ngel NyakiLand use in the study area

Location	Number of animals	Herder	Owner	Last observed grazing	Herder interviewed	Approximate area of reserve used	Grazing reserve in wet season	Frequency of reserve use	All day or part thereof
1	18	1	A	Throughout dry season	N	336 ha	?	Daily	Mostly all day
2	50	2	B	Throughout dry season	N		?	Daily	Mostly all day
3	18	3	C	07/11/2008	N	152 ha	?	4 days p/w	Morning
	20	15	L	22/11/2008	N		?	2 days p/w	Morning
4	25	4	D	23/10/2008	Y	133 ha	Y	Daily	All day
5	23	5	E	Throughout dry season	Y	114 ha	N	Daily	All day
	50	6	N	10/11/2008	Y		?	?	?
6	40	7	G	Throughout dry season	Y	20 ha	Y	6 days p/w	All day
7	35	8							
	45	9		23/11/2008	Y	78 ha	N	5 days p/w	Morning or afternoon
	25	10		Throughout dry season	Y		N	5 days p/w	Morning or afternoon
					N		N	Only seen once	All day

8	64	11	H	Throughout dry season	N	30 ha	?	3 days p/w	Morning or afternoon
	?	12	I	?	N		Y	Daily	All day
9	25	13	J	06/11/2008	N	322 ha	?	?	?
10	23	14	K	Throughout dry season	N	9 ha	?	Daily during late dry season	Afternoon

Six general classes of land-use were identified in the study area: protected areas (Kurmin Danko and Ngel Nyaki), settlements, plantations and farms, pasture areas on the plateau where graziers hold rights of ownership and lowlands, where graziers hold grazing permits (Figure 5-3). Some areas, however, belong to multiple land-use classes. When the locations of settlements and cattle tracks are considered, it becomes apparent that the protected areas are also used as rangeland. Additionally, the township of Yelwa falls into multiple land-use classes. The functional unit of Yelwa Township includes the surrounding agricultural fields and eucalyptus plantations. The pastures of the plateau are interspersed with settlements of varying sizes, crop fields (usually maize), eucalyptus plantations and riverine forests with semi-protected status. Like the plateau, the lowlands also have varied uses with pasture being the most important for this study. Case studies are presented considering the land-use of the northern portion of Ngel Nyaki Forest Reserve in addition to Fulani-owned properties neighbouring the eastern and northern boundaries of the reserve.

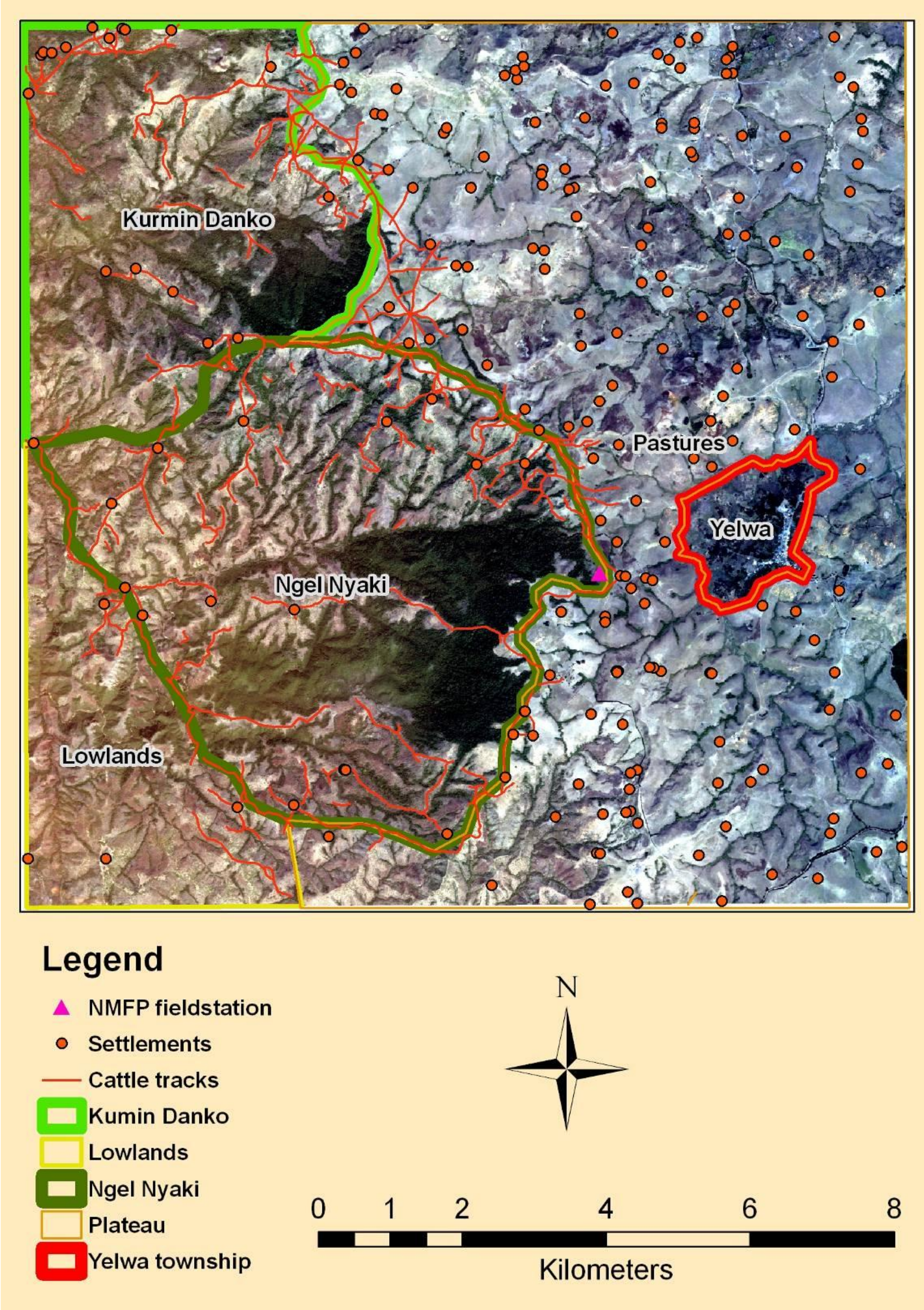


Figure 5-3: Land compartmentalisation in the study area

5.4.2 Case study of land-use and land tenure around Ngel Nyaki

Efforts have been made to give an indication of the portions of the northern part of the reserve used by different herders, as they consider these areas to be their property for all management purposes.

Interviews and observations indicated that the northern part of the reserve is compartmentalised in the same manner as the land outside. Observations made in section 5.4.1 show, that individual herds are always seen in a particular area rather than moving through the whole of northern Ngel Nyaki Forest Reserve. Herders stated in interviews that they only graze up to certain landmarks, such as rivers or gorges. Herders also indicated whether they were alone in grazing a particular area or if the area was grazed by other herders as well. In the latter case they were able to name the other herders as they shared the same employer. Every landowner has ‘his’ area in the reserve where his herders take their herd and breaches of these arrangements result in severe disputes between the families concerned. Interviewees reported of such a dispute between landowners P and F that resulted in F erecting a fence that prevents cattle from landowner P using the access path regularly used by F to enter the reserve.

However, access rights for herders across properties not belonging to his employer exist. For example, herders are generally allowed to pass through any property along routes indicated for transhumance. Additionally, herders of landowner U frequent the reserve, although U has no direct access to the reserve, indicating more complex access rights are in place.

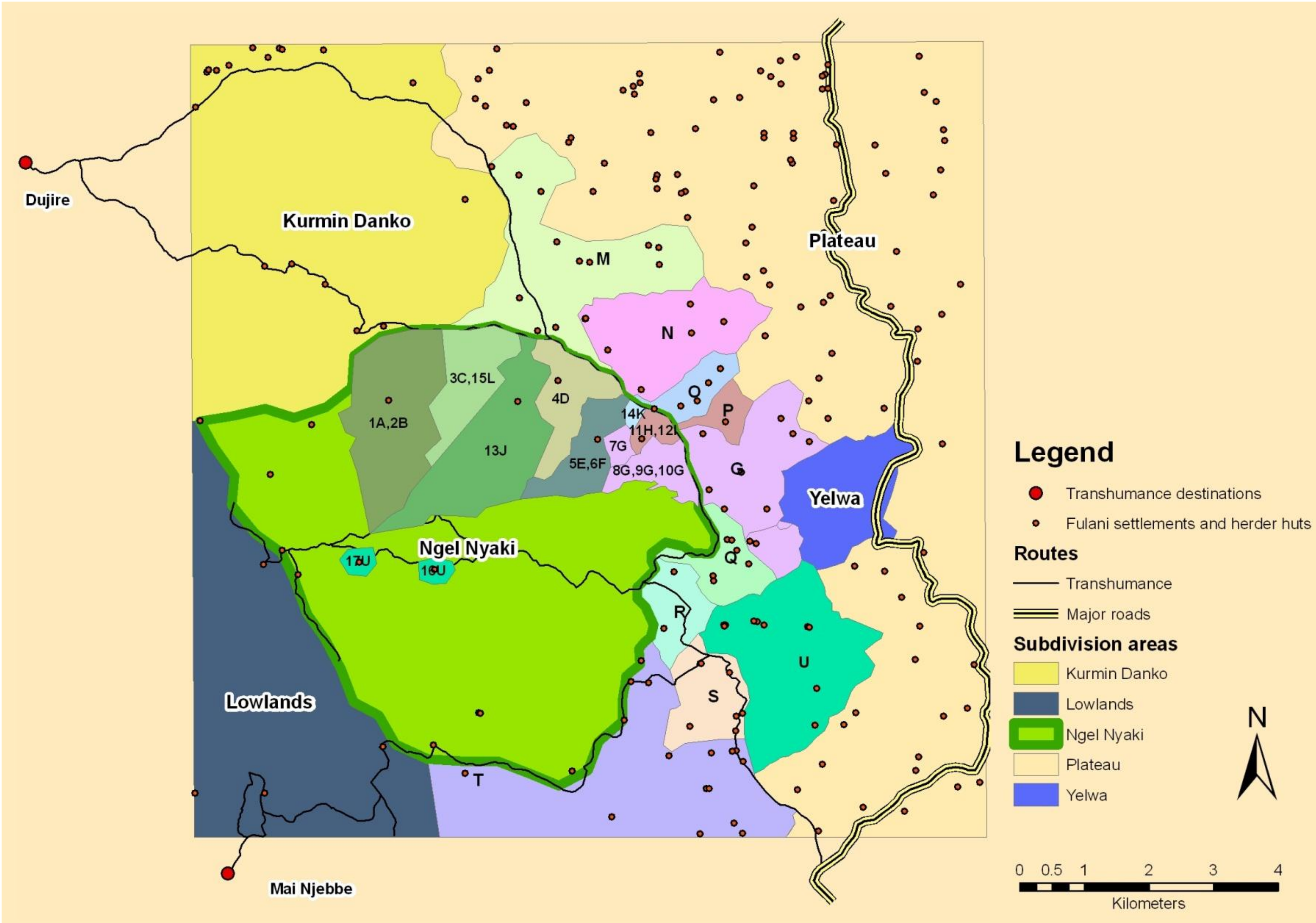


Figure 5-4: Thematic map of land-use, land tenure and important transhumance routes around Ngel Nyaki. An approximation of reserve allocation to each herder is indicated using the coding for each herder (1 to 17) and cattle owner (A to L). The approximate boundaries of Fulani properties on the plateau are also indicated with the respective owner coded from M to U.

5.4.3 Case study of land use on Fulani-owned properties neighbouring Ngel Nyaki

5.4.3.1 Stocking rates on Fulani pastures

Estimated stocking rates varied greatly between landowners (Table 5-2) ranging from 54.7 TLU/km^2 to approximately 201 TLU/ km^2. All but two landowners assessed use the reserve for grazing. Average stocking rates were 105 TLU/km^2 (+/- 51 TLU/km^2) and the median stocking rate 78.5 TLU/km^2.

5.4.3.2 Land use distribution on Fulani properties

The majority of land use on all Fulani owned properties neighbouring Ngel Nyaki Forest Reserve was rangeland (Table 5-3, Figure 5-5). M and T own the largest properties in the area, N and G medium sized properties, Q, R and S smaller properties, while O and P have by far the smallest properties.

Crops are grown on all properties. The total area under cultivation on the surveyed Fulani properties equates to 59.7 ha. Although maize constitutes the only large scale crop on Fulani farms, a few pumpkins, beans, bananas, guavas or avocados may also be grown for variety. The crop residues (especially from maize) are highly valued as additional cattle feed during the dry season. The properties of N and T contained the largest extents of cultivated fields while Q and R show the least cultivation of crops.

Eucalyptus trees are also commonly planted. The increasing firewood and building material needs experienced by Fulani families has prompted many to devote more of their land to eucalypt plantations. Eucalypt plantations often took the form of ‘living fences’ used to define property boundaries between different landowners. M and O did not have any eucalypt plantations on their land, but most own at least a small plantation. G had by far the largest eucalypt plantation among all landowners in the case study. A total of 7.2 ha are used for eucalypt plantations across all properties surveyed.

Table 5-2: Characteristics of different land owners, their herds and their properties

Land owner	Clan	Approximate property extent [ha]	Grazing reserve	Min. Number of herders	Inferred minimum cattle numbers[13] [head]	Inferred minimum stocking densities [head/km^2]	Inferred minimum stocking densities [TLU/km2]
G	Daurankoen	325	Yes	11	466	143	110.1
Q	Butankoen	125	No	6	254	203	156.3
R	Mbawankoen	120	No	2	85	71	54.7
U	Mbawankoen	479	Yes	10	424	88	67.8
O	Mbawankoen	81	Yes	5	212	261	201
P	Daneji	50	Yes	1	42	85	65.5
S	Mbawankoen	160	Yes	7	297	185	142.5
T	Mbawankoen	703	Yes	17	720	102	78.5
N	Mbawankoen	325	Yes	7	297	91	70.1

[13]Inferred minimum cattle number estimations are subject to a standard error of 10.3%. The number describes the total of cattle a given landowner owns given average herd sizes per herder and number of herders counted on a landowner's property.

Table 5-3: Land allocated for grazing, farming and eucalypt plantations for each property

Landowner	Property area [ha]	Cropland [ha]	Eucalypt plantations [ha]	Natural forest vegetation [ha]	Rangeland [ha]
M	543	7.6	0.0	37.0	498
N	325	11.8	0.8	20.7	291
O	81	3.4	0.0	5.2	72
P	50	6.1	0.5	1.6	41
G	325	7.9	2.5	17.1	297
Q	125	1.8	0.3	11.2	111
R	120	2.3	1.1	10.6	106
S	160	4.7	1.1	11.8	142
T	745	14.1	1.1	78.2	651

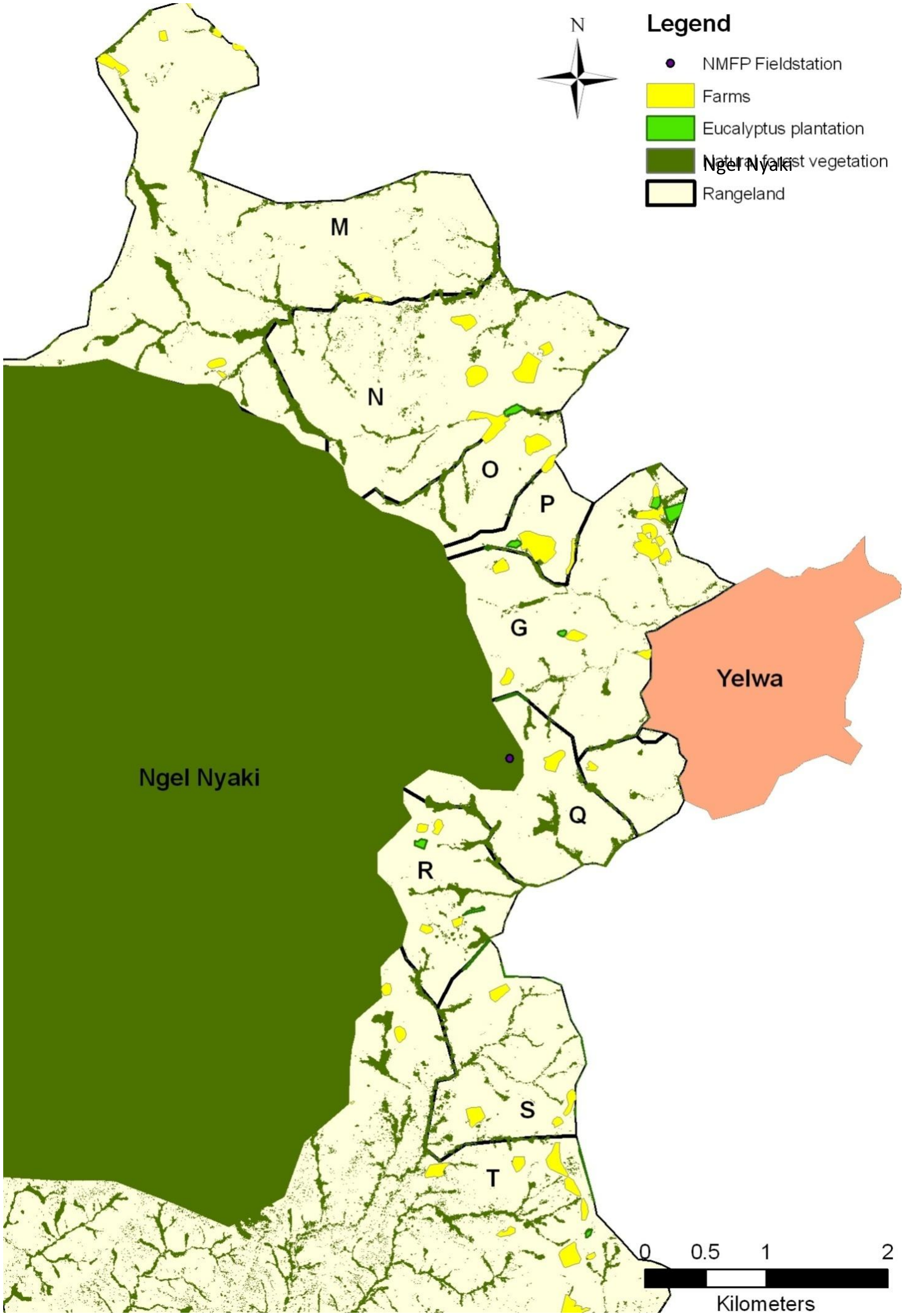


Figure 5-5: Land use of Fulani properties surrounding Ngel Nyaki. Land ownership is indicated with letters G and M-T.

5.5 Discussion

5.5.1 Limitations

Observing cattle herds in the northern area of Ngel Nyaki Forest Reserve faced difficulties presented by its landscape. Despite attempting to do so, it proved impossible to obtain a clear view of the whole northern portion of the reserve from any ground location. Cattle herds under observation frequently disappeared from view in forested patches or valleys and made asserting clear boundaries to a particular herder's territory difficult. Thus, the areas marked on the map are not definite, but provide a good estimation of the spatial extent and location where identified herds have regularly been spotted.

Similar obstacles were encountered when delineating Fulani properties for the case study. The parcels of land bordering Ngel Nyaki to the north and east are each under the control of the senior patriarch of a Fulani family. These properties are usually distributed among the patriarch's sons, with elder sons usually receiving a bigger share. When the land cannot be further divided (because the individual parcels would not be viable by themselves) the younger brothers often take up employment as herders on an older brother's land. Still, while the patriarch lives, he retains power over herd and land management decisions. The land divided among the sons may be marked with fences while other families manage the property as a whole. Some herders gave the name of the patriarch and others the name of the son as the 'owner' of the pasture. This often makes it difficult to attribute the ownership of a certain parcel of land to the right person and provides some room for error in the assumed property extents.

Many herders observed grazing in northern Ngel Nyaki moved to the lowlands before interviews could be conducted. Others were only observed entering or leaving the reserve through a telescope, but neither their, nor their employers' identities could be confirmed. While other observations suggest it is unusual for herders to cross a property other than their employer's to access the reserve, this possibility cannot be ruled out. Therefore, a herder seen to enter the reserve at a particular location, cannot automatically be ascribed to the person owning the adjacent land at that location, although this circumstance is very likely.

The RGB and false colour resolution of the Quickbird imagery is high enough to distinguish herders' huts in the grassland. However, it is possible that a few huts escaped detection (false negative), while recently vacated huts were nevertheless considered to be home to a herder and his herd (false positive). Furthermore, it is impossible to say how many herders were living in the large family compounds of landowners, although it can safely be assumed, from knowledge gained in the field, that at least one herder lives in each large family compound. Due to these uncertainties, it is impossible to be certain of the exact number of herders employed by a landowner. However, given the high probability of visible huts being inhabited by herders, for at least part of the year, the reported numbers provide a good estimation of the minimum number of herders employed by each landowner.

5.5.2 Discussion of results

5.5.2.1 Dry season stocking rates in northern Ngel Nyaki

The dry season stocking rate in northern part of Ngel Nyaki Forest Reserve is estimated at a minimum of 18.6 TLU/km^2 (5.4 ha per TLU). This is a rough estimate calculated from the total area visited by the herds including, areas with very steep slopes or dense forest, unsuitable for grazing. Accounting for effective grazing area would raise the reported stocking rates even higher. On the other hand, not all cattle grazing in the reserve for the duration of the dry season were grazing there every day. Usually stocking rates assume the constant presence of grazers and so the reported stocking rate would have to be adjusted downward to compare it with other studies or data on carrying capacity. This may be of importance for future studies with more in depth focus towards grazing capacity and intensity in this region, however, the rough estimate of 18.6 TLU/km^2 is sufficient for the purposes of this study.

Data drawn from worldwide examples suggest that dry season carrying capacities of semi-arid regions range from around 7.7 TLU/km^2 to 3.1 TLU/km^2 (13–32.5 ha per TLU) (de Leeuw & Tothill 1990). Even in the highly productive forest reserves of north-western Nigeria dry season carrying capacities do not exceed 7.7-15.4 TLU/km^2 (6.5-7.7 ha per TLU) (Ademosun 1973). When these figures are compared with the estimates for the northern area of Ngel Nyaki Forest Reserve, it becomes apparent that although classed as protected, this area is very likely overstocked (even for a pasture) and facing resultant degradation through overgrazing.

That all landowners with properties that share a boundary with Ngel Nyaki Forest Reserve, providing direct access to the reserve, graze there, can be explained by two pragmatic drivers: (1) the persistence of fresh forage in the reserve for longer into the dry season than on home pastures and (2) additional grass resources available to be utilised within the reserve. The first driver allows cattle to have fresh forage for longer allowing transhumance to be delayed, or even making it unnecessary altogether in some cases. The second driver allows landowners to lower grazing pressure on their home pastures (on their property) or to own a larger number of cattle. Four of the landowners however, did not fit this model. Two landowners without direct access to the reserve due to the lack of a shared boundary, utilise the reserve for cattle grazing by employing herders living in temporary huts within the reserve for at least the duration of the dry season. The other two cattle owners live adjacent to the reserve, but are prevented from grazing within the reserve by steep slopes and thick forest all along the shared boundary in one case (R) and a fence surrounding the area of the NMFP field station in the other case (Q). In absence of direct access to the reserve, these landowners do not own cattle grazing inside the reserve, however (unlike U). Future research should aim to illuminate the procedures behind gaining access to the reserve and why some Fulani who have no direct access path to the reserve graze there, while others do not.

Fulani patriarchs have bribed government officials to gain access to parts of the reserve in the past, and it seems likely this still happens today. This could explain the compartmentalised pattern of use found in the reserve where initially a free-for-all scenario may be expected.

5.5.2.2 Stocking rates on Fulani owned properties

Carrying capacities between 31 TLU/km^2 (3.3 ha per TLU) and 69 TLU/km^2 (1.6 ha per TLU) have been reported for the highlands of Ethiopia and Eritrea (Nyssen *et al.* 2004). These areas are similar in vegetation type, precipitation and temperature to the study site allowing suitable comparisons to be drawn. It is important to note however, that Nyssen *et al.*'s (2004) reported carrying capacities are calculated on an annual basis and hence do not take into account the substantial differences in biomass productivity during wet and dry seasons. Hall (1971) estimates carrying capacities between 12.8 and 15.4 TLU/km^2 (7.8-6.5 ha/TLU) on the Jos Plateau, Nigeria, also with very similar climatic conditions to the Mambilla Plateau.

As these two were the only studies found estimating carrying capacities for tropical montane regions, other studies in different climatic regions have also been included for comparison:

Carrying capacity in semi-arid areas of sub-Saharan Africa has been estimated at an annual average of 5-8 TLU[14] per km^2 for low fertility soils over basement complex and 800-1100 mm annual rainfall (de Leeuw & Tothill 1990). Dry and wet season biomass productivity varies substantially. Carrying capacities in this region range from a low 1.5-4 TLU / km^2 in the dry season, through to 25 TLU / km^2 in the wet season.

Much of the Mambilla Plateau experiences annual rainfall in excess of 1700 mm, much greater than described for the semi-arid environments above, where vegetation faces drought conditions throughout much of the year. The wet season on the plateau is reliable, plentiful and lasts for at least 7 months. These rainfall characteristics are therefore more comparable to the Nigerian subhumid zone (Sumberg *et al.* ; Tothill 1986; Ikwuegbu & Ofodile 1994; Woji, Little & Ikwuegbu 1994) than to the semi-arid zone. The amount of rainfall occurring on the Mambilla Plateau could even place it in the humid zone (Tothill 1986). However, the marked dry season and lower temperatures of the highlands make comparison with the sub-humid zone more relevant, especially in terms of biomass productivity, which is negatively impacted by the lower temperatures occurring at higher altitudes and the prolonged dry season. Therefore, carrying capacity in the study area should lie between those for semi-arid sub-Saharan Africa and those of the subhumid zone. The biomass productivity of the Nigerian subhumid zone would suggest a maximum average annual carrying capacity of 65 TLU/km^2 (de Leeuw & Tothill 1990); with carrying capacities of over 77 TLU/km^2 reported for the Forest Reserves of north-western Nigeria during the wet season (Ademosun 1973).

When the figures found in the literature are compared with the estimated minimum stocking rate of the region (Table 5-2) it appears these pastures are very likely severely overstocked during most of the year. The average stocking rate has increased from 83 TLU/km^2 in 1966 (Hall 1971) to approximately 105 TLU/km^2 in 2008.

[14]TLU = Tropical Livestock Unit (1 TLU = 250 kg), 100 head of cattle = 77 TLU (DeLeeuw, 1984)

The tendency of overstocking pastures in tropical highlands is common. Lambi (2009) for example, reports massive overstocking, pasture degradation and erosion in the western highlands of Cameroon, associated with average stocking rates of 257 TLU/km^2 (0.23 ha/TLU). This region receives in excess of 1800mm of rainfall annually with a 0-3 month dry season. Current stocking rates around Ngel Nyaki are not quite as high, but population increases may lead to an increase in stocking rate on the Mambilla Plateau, resulting in 'environmental destruction' described in Cameroon's Bamenda Highlands (Lambi 2009). Davies (1946) reported stocking rates of 118 TLU/km^2 (0.85 ha/TLU) on the Jos Plateau, Nigeria, also in combination with severe environmental degradation.

Table 5-4: Overview of reported carrying capacities (TLU/km^2) found in the literature

<table>
<tr><th rowspan="2">Area</th><th rowspan="2">Described by</th><th rowspan="2">Annual rainfall</th><th rowspan="2">Soils</th><th colspan="2">Arid/semi-arid climate</th><th colspan="2">Sub-humid climate</th><th rowspan="2">Montane climate</th></tr>
<tr><th>Dry season</th><th>Wet season</th><th>Dry season</th><th>Wet season</th></tr>
<tr><td>Jos plateau, Nigeria</td><td>Hall 1971</td><td>n/a</td><td>Nutrient poor</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>12-15</td></tr>
<tr><td rowspan="3">Zimbabwe, West Africa (general), Kenya, Niger, Mali, Ethiopia</td><td rowspan="4">de Leeuw & Tothill 1990, de Leeuw & Tothill 1984</td><td>400mm</td><td>n/a</td><td colspan="2">14-25</td><td rowspan="3">n/a</td><td rowspan="3">n/a</td><td rowspan="3">n/a</td></tr>
<tr><td>~900mm</td><td>Nutrient rich</td><td colspan="2">25-33</td></tr>
<tr><td>~900mm</td><td>Nutrient poor</td><td colspan="2">5-8</td></tr>
<tr><td>Subhumid zone, Nigeria</td><td>~1500mm</td><td>n/a</td><td></td><td></td><td colspan="2"><65</td><td></td></tr>
</table>

<table>
<tr><td rowspan="2">Forest Reserves, North-western Nigeria</td><td rowspan="4">Ademosun 1973</td><td>~1000mm</td><td>n/a</td><td>8-16</td><td>>77</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td><1000mm</td><td>n/a</td><td colspan="5">13-28</td></tr>
<tr><td>Northern Guinea Savannah, Nigeria</td><td rowspan="2">n/a</td><td rowspan="2">n/a</td><td colspan="5" rowspan="2">5-19</td></tr>
<tr><td>Grass savannahs, Chad</td></tr>
<tr><td>Highlands, Ethiopia and Eritrea</td><td>Nyssen et al. 2004</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>31-69</td></tr>
</table>

5.5.2.3 Other land use

Large farms and labour intensive agricultural pursuits as well as solid houses and long term investments like eucalyptus plantations are absent from the reserve, while these significant investments are an obvious feature on Fulani owned properties. This indicates that the Fulani are confident in their land tenure outside the reserve. At the same time limiting their activity within the reserve to only small scale investments is indicative of the tentative nature of this land tenure.

The trajectory of natural forest loss replaced by plantation forests is not an unusual land use change and has been documented in a number of other studies in tropical montane settings (Imbernon 1999; Fox 2005; Farley 2007). The drivers leading to an increase in these plantations are most likely to come from forest scarcity in the region, following forest transition theory (Farley 2007). The only relatively large forests in the area are found within a protected area, while small riverine forests also enjoy a limited form of protection. The absence of access roads and the hilly nature of the study area encourage plantation forests to be established either close to the homestead for personal use as firewood and construction timber or close to the one main access road on the Mambilla Plateau for easy transport to markets as an additional source of income. The increasing number and extent of eucalypt plantations in the study area marks the beginning of a forest transition.

The most common land use change found in tropical montane regions is conversion from forests to agricultural land, mostly for slash-and-burn farming. Most of the study area, as with the rest of the Mambilla Plateau, is owned by pastoralists and ranchers, mostly Fulani. The Fulani do not traditionally farm and today Fulani agro-pastoralists often employ local agriculturalists to farm for them in exchange for a share of the crop. Indigenous farming communities on Mambilla are often landlocked, only able to establish farms in the immediate surrounds of their villages or after gaining permission to farm on a Fulani landowner's land. Therefore, farming communities' activities are spatially separated and disconnected from the protected area (Korndoerfer 2010, MacDonald 2007). Although some poaching occurs, large scale encroachment of agricultural land use in the protected area is unlikely in this setting.

5.5.2.4 Population pressure and scope for intensification of agriculture and economic development

Due to the poor soils of the study site, few flat surfaces and lack of interest and capital for investment in chemical fertiliser, alternative farming methods (e.g. Permaculture) or machinery, farming methods are far from being modern, intensified high-input / high-output agricultural systems. In addition to a lack of modern farming techniques, effective traditional farming systems previously employed by the Mambilla tribe such as fertilising fields by planting the soil enriching shrub 'Yom' and terracing to reduce erosion, have largely been abandoned (Korndoerfer 2010).

On the Mambilla Plateau, the human population is steeply increasing among all ethnic groups, as many families count more than 10 children per woman, with most surviving to adulthood. Agriculture will have to be intensified[15] (in landlocked farming communities) and extensified[16] (for Fulani properties) in order to feed this growing population. Similar trends have been found in other montane areas (Imbernon 1999; Arredondo-Leon, Munoz-Jimenez & Garcia-Romero 2008). Arredondo-Leon *et al.* (2008) remark that even in areas showing positive trends towards conservation (forest regeneration), as is occurring in the former agricultural fields within Nyaki Forest Reserve (abandoned in 1974 when people were evicted from the reserve), the risk of these areas being reactivated for agricultural or pastoral land use increases with increasing population pressure.

Cash crops are another land use through which rural communities seek economic development (Imbernon 1999; Fox 2005; Farley 2007). This occurs on the Mambilla Plateau primarily in the form of selling timber sourced from fast growing eucalypt plantations throughout the study area and to a lesser extent by growing coffee and tea.

Izquierdo (2009) believes that those tropical montane regions that offer opportunities for modern intense agriculture, follow a rural-urban migration trend and orientate the local economy towards industrial and service sectors may expect land use transitions towards ecosystem recovery. If this holds true, then the future of the study area is looking grim indeed, as none of these factors are currently applicable to this area. Rearing cattle and other livestock, subsistence farming and Eucalypt plantations cannot be abandoned as these are (with a few exceptions) the only means of generating livelihoods in the study area.

5.5.2.5 Effect of land use practices on the protected area

The study area of Kintz *et al.* (2006) in the tropical Andes constitutes a very similar setting to my study area. It includes a protected area (Rio Abiseo National Park), a landscape with moist and wet montane forest cover at a similar elevation and with similar amounts of annual precipitation. There is an extended dry season and even the land use patterns are very similar to the Mambilla Plateau. In the Andes, as on the Mambilla Plateau, the protected area in question has regularly been grazed and burnt. Interestingly, in Rio Abiseo National Park, land use patterns, against all expectations, led to a net increase of wet montane forest within the reserve, but led to a large decrease in moist montane forest in the buffer zone of the reserve. Kintz *et al.* (2006) propose that fire regimes may have been altered in a way that allowed natural regeneration, after creation of the reserve. What effects past land-use has on the study area in Nigeria is explored in chapter 3.

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[15] more crops produced per farming area

[16] more area dedicated to cropping

5.6 Conclusion

A large number of cattle have been observed grazing in the Ngel Nyaki Forest Reserve throughout the dry season. These herds graze in clearly defined areas, the boundaries of which are respected by all herders. A clear tendency was found for cattle owners owning land adjacent to the reserve to send their herders into the reserve to use it as an extension of their pastures, although not all herders using the reserve came from adjacent properties. Two cattle owners who own land non-adjacent to the reserve employed herders that live in temporary huts inside the reserve for the dry season, which seems to be another socially acceptable way of gaining access to the reserve's resources. Pertaining to the goals of this section, the findings can be summarised thus:

<u>Land area used for grazing, silviculture, agriculture and unmodified land</u>

- The beginning of a land use transition towards diversification through agropastoralism and silviculture has been demonstrated in the case study of Fulani properties surrounding the reserve and even more so in the case of the agricultural tribes, living in Yelwa village.
- Grazing is by far the dominant land use in the study area. However, there are also significant areas under agricultural and silvicultural use, consolidating the classification of the local Fulani as settled or transhumant agropastoralists.
- On Fulani owned land, only small amounts of unmodified vegetation is found.

<u>Grazing intensities inside and outside the reserve</u>

- Stocking rates in the northern part of Ngel Nyaki Forest Reserve during the dry season are higher than carrying capacities usually reported for dry season grazing, suggesting this area is overgrazed.
- Stocking rates on Fulani properties are in most cases higher than carrying capacities usually reported for tropical montane grasslands, suggesting these are also overgrazed.
- Increasing population pressure[17] will create the need for further agricultural and pastoral intensification and extensification in the future.

<u>Distribution of properties</u>

- Property sizes vary considerably between landowners.

[17] Yelwa village experienced an increase in population from 16 to approximately 450 households over 20 years (Korndoerfer 2010).

- Cattle owners owning land adjacent to the reserve with a boundary that allows cattle access, use the reserve as additional grazing area.

- Some cattle owners, who own land not adjacent to the reserve, still use the reserve as an additional grazing area.

<u>Mapping of important migration routes</u>

- Four major routes were found and mapped in the study area. One follows the northern boundary of first Ngel Nyaki and then Kurmin Danko forest while one follows the southern boundary of Kurmin Danko, separating it from Ngel Nyaki forest. Another route cuts through the core forest within Ngel Nyaki FR and the last leads along the southern boundary of Ngel Nyaki FR.

A major change in land use can be expected by 2050 due to the effects of climate change (Kristjanson *et al.* 2003). It is predicted that by 2050 the climate on the Mambilla plateau will have changed from a typical tropical highland to a sub-humid or humid climate (Kristjanson *et al.* 2003). This means pastoralists are likely to face higher costs related to cattle rearing, through vaccinations and higher rates of sickness and death among their cattle due to increased spread of disease vectors. It is difficult to predict whether this prospect is likely to lead to an intensification of production systems to secure profits in the face of higher costs or whether the abandonment of pastoral livelihoods will result.

Chapter 6: Local environmental constraints to grazing and cattle rearing

6.1 Grass Productivity

6.1.1 Introduction

Four main factors have been identified as important in determining the movement patterns of nomadic and transhumant pastoralists: (1) The spatial and temporal availability of forage (Basehart 1977; Oba & Lusigi 1987; Bassett 1988; Blench 2001; Hampshire 2006; Adriansen 2008), (2) the availability of salt and forage with high nutritious value (Riesman 1977; Roath & Krueger 1982; Bailey *et al.* 1996; Blench 2001; Fuhlendorf & Engle 2004), (3) the availability of water sources (Western 1975; Roath & Krueger 1982; Bailey *et al.* 1996; Blench 2001) and (4) the desire to minimize livestock exposure to disease vectors (Bassett 1986; Hurault 1998; Blench 2001; Brockington 2002; Boutrais 2007).

Additional factors which influence grazing on a smaller scale include toxin concentration in forage, range topography, microclimate, temperature and herd social interaction (Bailey *et al.* 1996). However, this thesis is only concerned with larger scale grazing limitations. Consequently, this chapter explores seasonal variations in forage availability in the study area. Before I expand on this topic further, I will review the four key factors influencing the movement pattern of nomadic and transhumant pastoralists.

6.1.1.1 Forage availability

Nomadic and transhumant pastoralist systems are mainly dependent on the above-ground net primary productivity (ANPP) of grasslands. However, for some pastoralists, tree and shrub foraging (browse) plays a major role in livestock management, particularly during dry seasons (Gautier, Bonnerat & Njoya 2005; Chakeredza *et al.* 2007).

ANPP of grasslands in different ecoregions is limited by different factors. Temperature is often the major limiting factor in cold environments (Epstein, Lauenroth & Burke 1997), precipitation in arid, semi-arid and seasonally arid climates (Fay *et al.* 2000), and nutrient ratios in regions with poor soils (Belsky 1994; Ludwig *et al.* 2001; LeBauer & Treseder 2008). However, ANPP is commonly co-limited by several factors at the same time (Hooper & Johnson 1999).

As this study was carried out in a seasonally arid region, water availability constitutes the principal limiting factor in the dry season (Fay *et al.* 2000; Swemmer, Knapp & Snyman 2007), while there may be a shift towards nitrogen limitation during the wet season (Belsky *et al.* 1993).

For most regions of the world, including savannah and steppe ecosystems, grass ANPP shows a positive linear relationship with annual rainfall (Le Houérou & Hoste 1977; Lauenroth & Sala 1992; Oesterheld *et al.* 2001;

Nippert, Knapp & Briggs 2006; Swemmer, Knapp & Snyman 2007). It has been demonstrated that, in addition to mean annual precipitation, temporal variability of precipitation (especially during the growing season) is also a crucial factor for explaining the annual productivity patterns of grasslands (Le Houérou & Hoste 1977; Fay *et al.* 2000; Nippert, Knapp & Briggs 2006). Precipitation and precipitation intervals are thought to influence ANPP through fluctuations in available soil moisture (Nippert, Knapp & Briggs 2006). Fay (2000) demonstrated that increased precipitation intervals considerably decreased soil respiration and soil moisture.

More recently it has been realised that not only *intra*-annual precipitation affects grassland ANPP but also *inter*-annual precipitation. Oesterheld (2001) found that ANPP fluctuations are buffered if years of low precipitation are interspersed with wetter, more productive years and amplified if the same rainfall regime (wet or dry) persists over several consecutive years. These findings are in accordance with evidence collected by Fay (2000) which indicates that changes in soil moisture at critical stages of soil microbial activity, biomass accumulation, plant life histories and other major ecological processes can trigger long term changes in ANPP in response to changed rainfall patterns.

Although these studies improve the theoretical knowledge base about general factors influencing ANPP, local studies are still required to build an appropriate mechanistic understanding of site-specific ecosystem function in relation to local grazing patterns (Swemmer, Knapp & Snyman 2007).

6.1.1.2 Availability of salt and nutritious forage

Supplementing cattle diets with salt is essential for cattle nutrition. Nutritional deficiencies (especially sodium deficiencies) develop easily and can contribute to poor animal health (Berger 1987). In nomadic or transhumant livestock management systems herders regularly take their herds to natural locations of high salt content. These locations may be several days journey from a settlement (Riesman 1977). In ranching and settled pastoralism salt is usually provided as “salt licks[18]”, (Martin & Ward 1973; Berger 1987; Blench 2001).

Cattle commonly also face poor nutrition through lack of available green (nutritious) forage during a dry season or drought (Bassett 1988; Blench 2001). Therefore, pastoralists around the world use fire to create post-burn green flushes that provide their livestock with a source of good nutrition in times of need (Western 1982; Wilsey 1996). The importance of these green flushes for cattle was made obvious by Fuhlendorf (2004), who found that cattle spend 75% of their grazing time on recently burnt pastures if given free access to both recently burnt and unburnt pasture. Wilsey (1996) also suggested that a good diet for herbivores with large body masses (like cattle) includes both dry senescent forage and fresh green shoots. The former constitutes the bulk of calorie intake, while the latter

[18] defined locations on the range where salt is regularly deposited for consumption by livestock

ensures good nutrition. Herbivores with smaller body masses have smaller calorie requirements and can therefore limit themselves to graze on small amounts of nutritious forage.

6.1.1.3 Availability of water sources

Within an otherwise suitable pasture, the distance from a water source ultimately determines the area utilised for grazing by cattle (Roath & Krueger 1982; Bailey *et al.* 1996). Research into cattle distribution patterns by Bryant (1982) found that cattle prefer to stay close to water sources because of free water access, a preferable microclimate, the availability of succulent forage and, as all these are available within a small area, the cattle are able to conserve energy. Therefore, it is not surprising that Blench (2001) reports access to water to be a prime determinant of nomadic or transhumant migration patterns across the world, and in arid and semi-arid environments water becomes an even more influential factor. While water availability is generally seen as beneficial for livestock, parasitic disease vectors are often prolific around water sources and increased risk of disease is associated with an increase in water supply and suitably high temperatures[19].

6.1.1.4 Disease vectors

As already mentioned in section 1.5.2 and chapter 4, it is of great importance for pastoralist herders to maintain a healthy herd. Therefore great care is taken to ensure that the herd is not exposed to epizootic parasites. For example, African pastoralists are well aware of the dangers of *Trypanosomiasis* to their herd and because of the seasonal reappearance of the disease with increasing precipitation, an intricate pattern of migration has evolved over time. This pattern strikes a delicate balance between the availability of water and forage and exposure to the Tsetse-fly borne disease[20], managing trade-offs between health risk through disease and health risk through malnutrition. This traditional migration pattern is less imperative now as modern veterinary services, in particular vaccinations, have made it possible for pastoralists to exploit areas not previously used during times when diseases like *Trypanosomiasis* would have decimated the herd.

As periods of high rainfall provide greater amounts of available forage and pastoralists are no longer driven away by increasing disease risk, they are able to increase their herd size considerably beyond what was possible in the traditional management regime. Therefore a modern pattern has emerged where pastoralists and their herds are clustering around regions with good access to veterinary care (Blench 2001). In these regions, due to the reduction of disease risks, the dependence on the other three controllers for grazing has increased.

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[19] conditions usually associated with the onset of the wet season

[20] both factors increasing with precipitation

6.1.2 Aims and Goals

This chapter quantifies the decline in standing grass biomass (the factor most relevant for grazing) during the dry season, which can be used to explain several of the observed pastoral management strategies used in the study area.

6.1.3 Site description

A general description of the study site can be found in chapter 2.1. Here only site characteristics that relate to grazing and ANPP are described.

In many respects, the climate and topography of the Mambilla Plateau make it a very desirable region for cattle rearing (Frantz 1981; Hurault 1998). The highland is Tsetse free and consists of undulating hills with predominantly gentle slopes, which cattle prefer to steeper slopes for grazing (Cook 1966). During the wet season there is ample rainfall and there are many spring-fed permanent streams to provide water. Due to the abundance of water during the wet season, forage is plentiful and landowners are able to stock their pastures with large numbers of cattle. However this forage availability changes in the dry season (Danburam, pers. comm.). The main reason is that rainfall is disproportionally distributed between wet and dry seasons. Although the Mambilla Plateau, and especially the study site, receives a high annual rainfall (in excess of 1700 mm/year), during the extended dry season (approx. 4 months from the beginning of November until March) it often receives no precipitation at all (Chapman & Chapman 2001). The result of this is that as the dry season progresses the majority of grasses become senescent, decreasing in nutrition and productivity. This research focused on grasses of the genus *Sporobolus*. These species constitute the overwhelming majority of grasses present on the plateau (Bawden 1966; Hurault 1998; Chapman, Olson & Trumm 2004).

After the site for the experiment was chosen, the area was fenced off to protect the plots from herbivory.

6.1.4 Methods

6.1.4.1 The productivity time series

In order to measure the declining forage stock for cattle during the dry season, the grass growth of *Sporobolus spp*. was measured through time, from start to end of the 2008/2009 dry season. To establish this productivity time series, a series of five 1 x 1 m plots were established at the beginning of the dry season (series 1) and then at regular intervals (every 18 days) throughout the dry season ending with series 9 (Table 6-1). The first series of five plots were established on October 29th. Grass growth was measured as increase in tiller height. These measurements were recorded every 6 days for the first 24 days after plot establishment and thereafter every 18 days. This same measurement pattern was repeated for each new series of plots established.

Table 6-1: Plot establishment dates

Series	Plots	Date established
1	1-5	29/10/2008
2	6-10	16/11/2008
3	11-15	04/12/2008
4	16-20	21/12/2008
5	21-25	08/01/2009
6	26-30	27/01/2009
7	31-35	14/02/2009
8	36-40	03/03/2009
9	41-45	20/03/2009

6.1.4.2 Plot distribution

The plots were established in tussock grassland, representative of ungrazed pasture in the area. The area was fenced off to prevent cattle from entering during the experiment. In order to avoid bias in the average growth rate for a certain aspect or slope, the five plots of a series varied slightly in these factors. This experimental design should allow assertions about productivity to be made for a larger area of the Mambilla grassland, although it may also have resulted in a slightly higher variability between plots. Two plots were south-facing, two north-facing and one was on a broad ridge. Similarly, two plots were set on steeper slopes, two on less steep slopes and one on a flat site. Each series of plots had the following combination:

- one steep/south,
- one less steep/south,
- one flat,
- one less steep/north and
- one steep/north.

The exact locations of the first five plots were then randomly assigned. A patch was deemed unsuitable if it contained more than 30% visible bare or rocky ground, and if the first assignment was unsuitable the random assignment was repeated. Subsequent plots of the same aspect/slope combination were then clustered around their equivalent from the first five established plots (Figure 6-1).

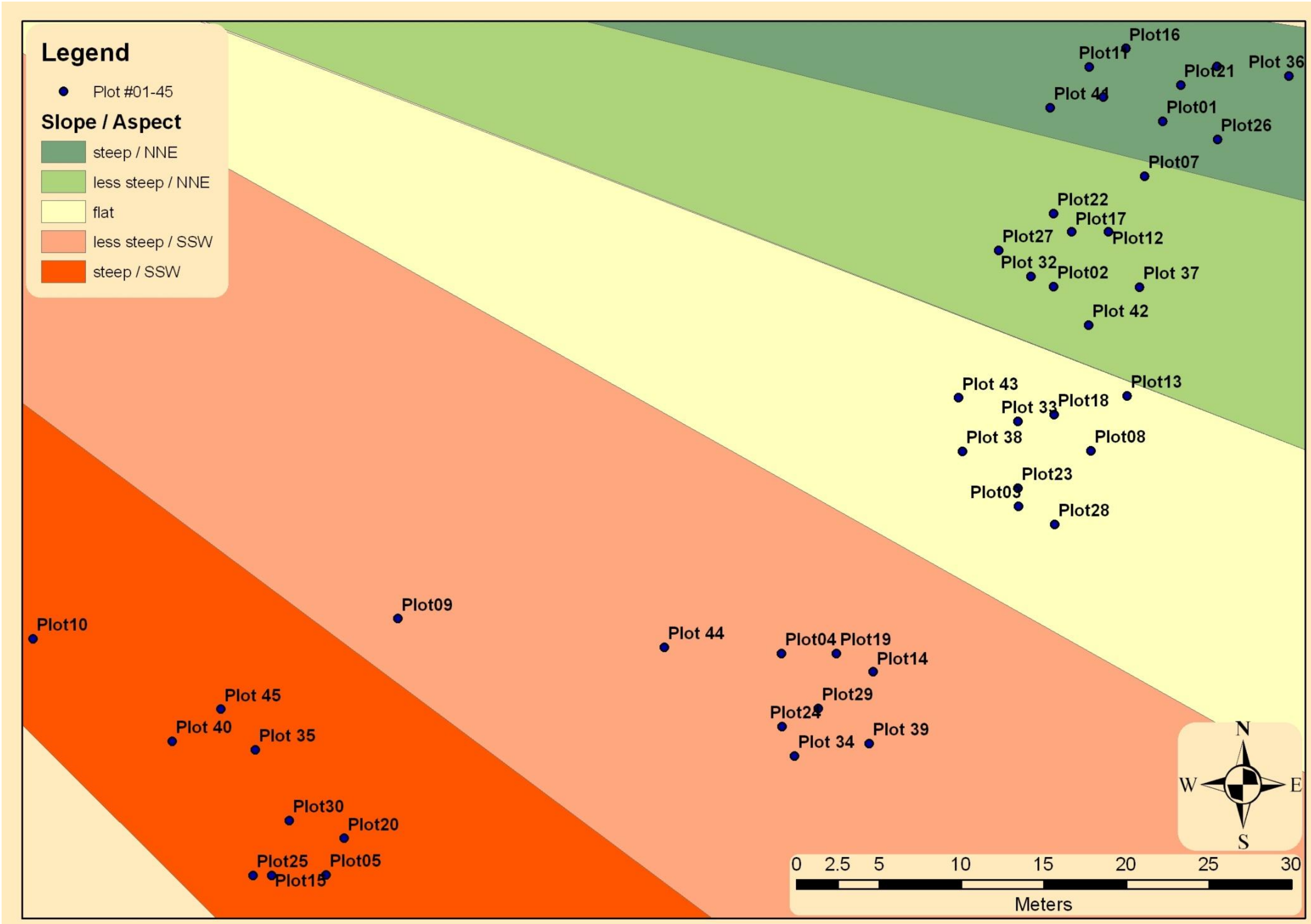

Figure 6-1: Locations of experimental plots (NNE-North-North-East, SSW- South-South-West)

6.1.4.3 Plot establishment

In establishing each 1x1m plot, the grass was cut to a length of approximately 5.5 cm. The cut grass was then removed from the plot (Figure 6-2). Measurements of grass growth were taken from the clearly visible cut mark to the tip of the newly grown grass blade. This was possible because the *Sporobolus spp.* displays primarily intravaginal tillering before becoming sexually reproductive. If two blades emerged from the same stem, the longer blade was measured (Figure 6-3).

Figure 6-2: The plot area was demarcated with four stakes; then the grass was cut to ~ 5.5 cm length.

Figure 6-3: Modality of growth; tillers were measured from the visible cutmark to the tip of the tallest blade

6.1.4.4 Sampling method

Overlaying the plot with a coordinate system and selecting the closest living blade to a random coordinate ensured randomness of the measurements (Figure 6-4). In each established plot, 50 random measurements were made every time that series was measured. No repeated measurement (on the same sampling day) of the same blade was allowed. The 50 measurements within a plot were then averaged and produced the average standing height of the plot at that particular point in time. The measurements were carried out by my field assistant, Ahmadu Manu.

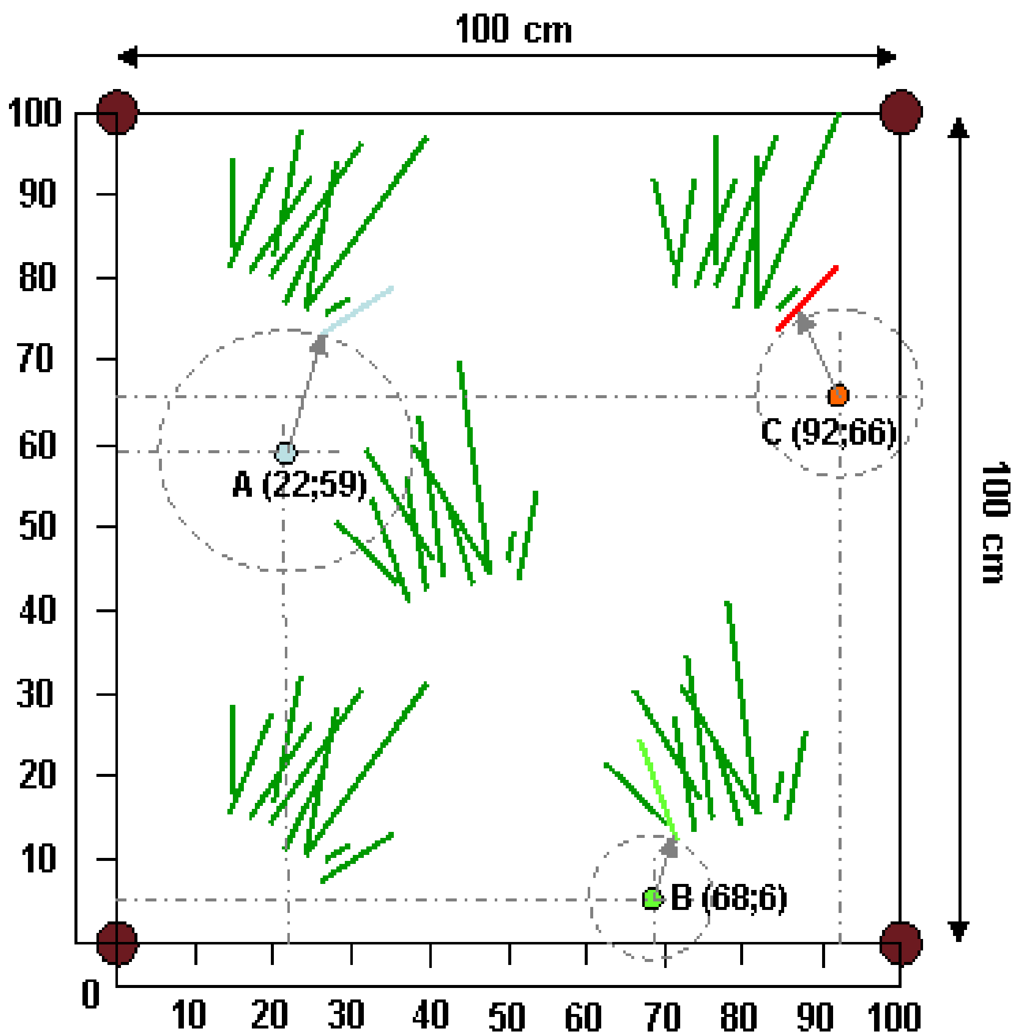

Figure 6-4: Sampling method

6.1.5 Results

6.1.5.1 Rainfall

The last regular rainfall of the 2008 wet season was recorded on the 26th of October 2008 (Figure 6-5). On the 4th of December 2008, an unseasonal precipitation event occurred, lasting 3 days and delivering ~25 mm of rain. Another rain event occurred on the 21st of January 2009. This event was considered negligible as it delivered only 0.6 mm of water and did not result in any measurable changes in grass productivity. The first rain of the 2009 wet season arrived on the 19th of March 2009.

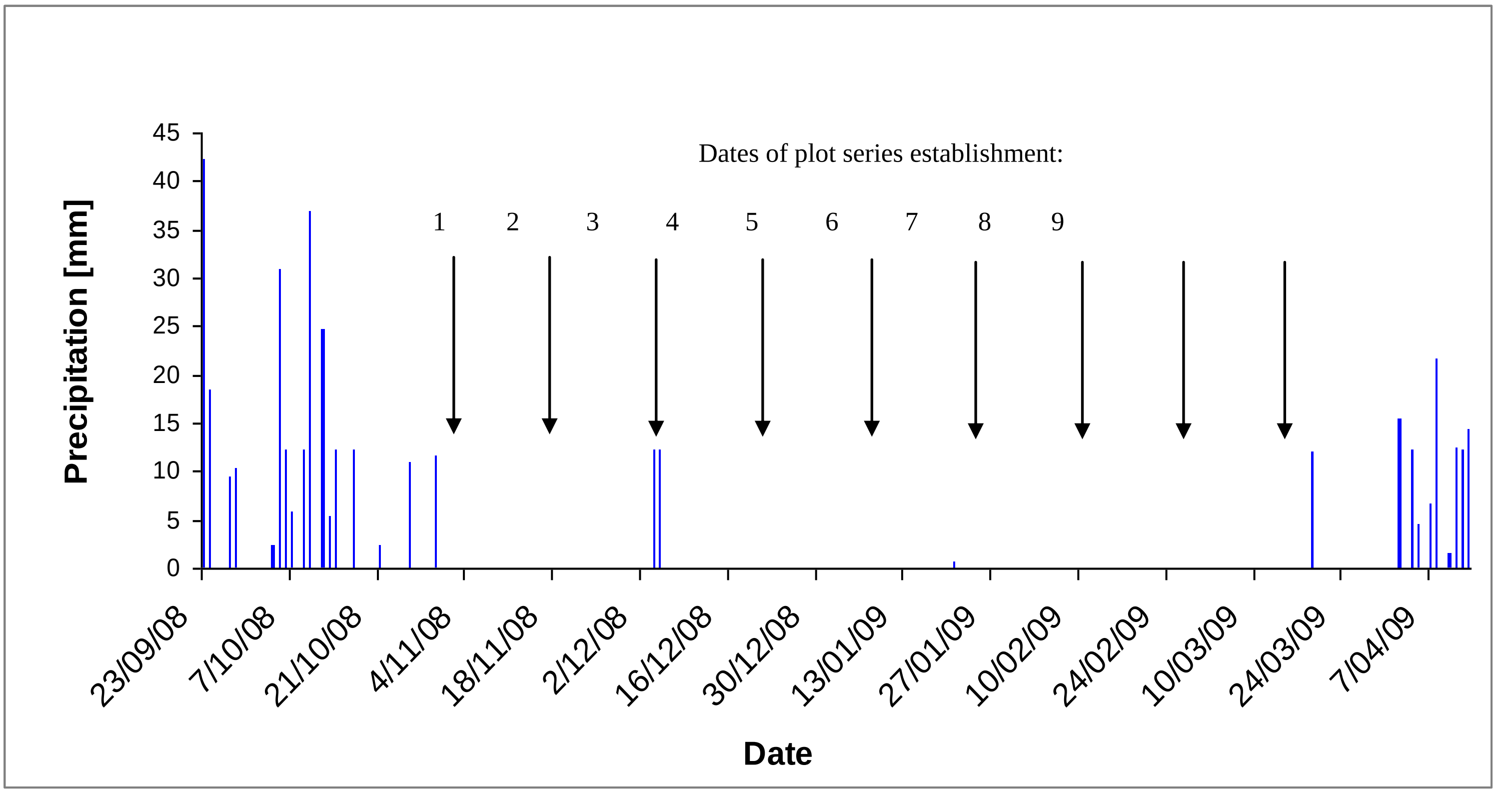

Figure 6-5: Plot series establishment in relation to precipitation at Ngel Nyaki from the end of the wet season 2008 to the beginning of the wet season 2009

6.1.5.2 Analysis of growth data

Due to an unexpected rainfall event and the accompanied growth spurt of grasses in series 1 and 2 at the beginning of December 2008 (see Figure 6-5 and Figure 6-7), these plots were excluded from the analysis of productivity. Series 9 was also excluded from the analysis as the first rains of the wet season started only a few days after plot establishment.

The remaining series 3 through 8 (Plots 11-40) were used for the analysis of change in maximum standing heights over time throughout the dry season. In each series, the average standing heights of each of the five plots were used as data points. Height was plotted against time to produce a distinct growth pattern for each series of plots. For the analysis a quadratic growth function was fitted to the data points (Figure 6-6). From the resulting functions, maximum heights, half maximum heights and the time the vegetation needed to reach these heights were extracted.

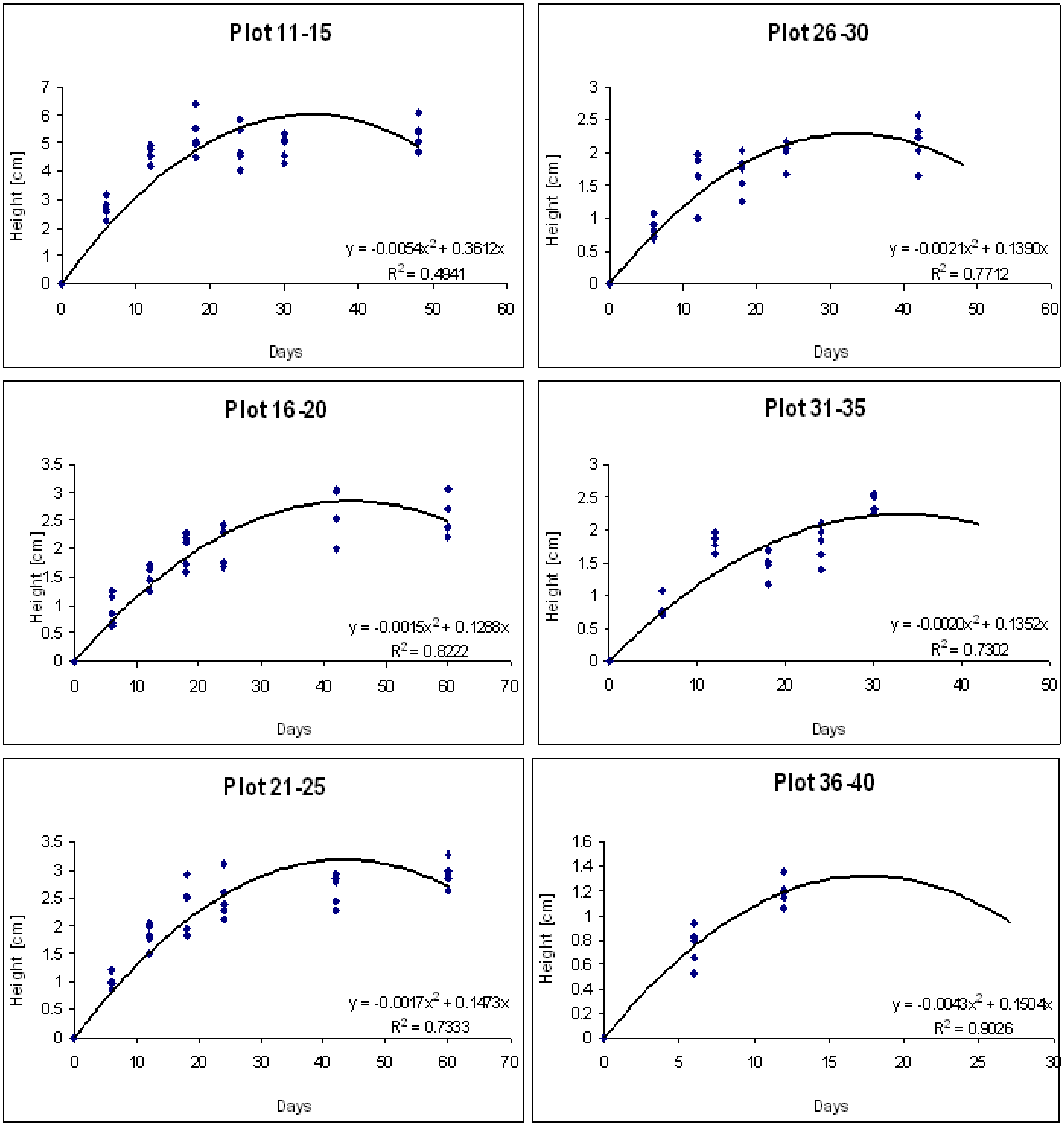

Figure 6-6: Polynomial fitted growth functions

The growth patterns of all plot series over the dry season were graphed (Figure 6-7). The first series was established in late October at the beginning of the 2008/2009 dry season while the vegetation was not yet showing any clear signs of senescence (series 1 & series 2). By early November, growth in these series had ceased. A freak rain event at the beginning of December lasting 3 days lead to a growth spurt of grasses in series 1, 2 and 3. From this rain event onward there was no significant precipitation recorded until the beginning of March. This was reflected in a decreased growth rate and decreased maximum standing height of series 3, 4, 5, 6, 7 and 8. The wet season started again very soon after series 9 was established, leading to prolific growth in this series. From the end of March onward, all plot series except 1, 2 and 3 showed a steep increase in productivity coinciding with the return of the rains. The three series constituting the exception had most likely already reached maturity; therefore no new growth could be detected with the chosen method. All plots show an initial sharp increase in standing height after cutting, however, the further into the dry season the plots were cut, the lower the maximum standing height.

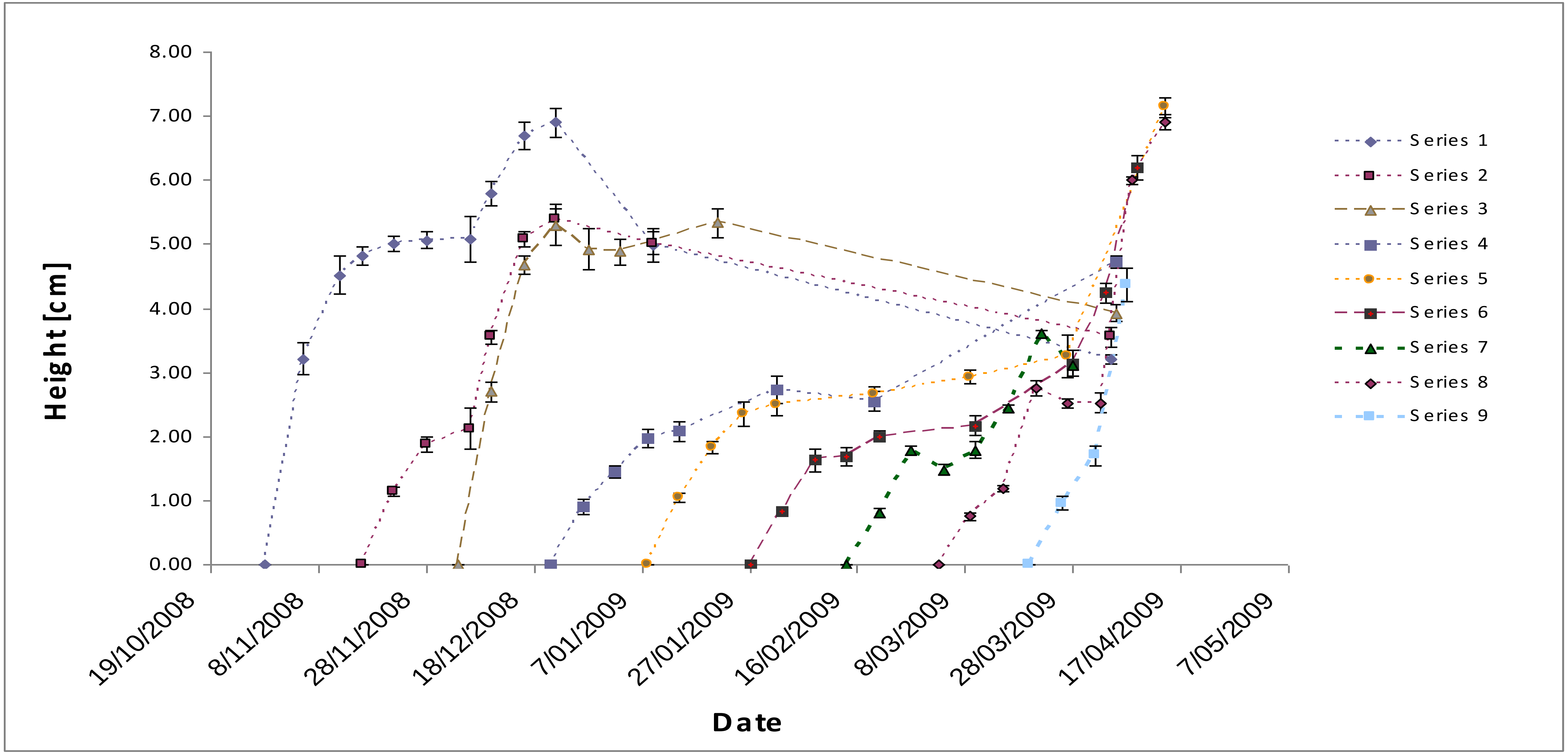

Figure 6-7: Grass growth pattern over the course of the2008/2009 dry season

Series 1 and 2 had already ceased growing when the unseasonal rain event reactivated the growth process (Figure 6-7). While this likely had important implications for grazing viability and pasture management, this second growth spurt cannot be immediately compared with the rest of the data series, where only one growth spurt and subsequent plateau phase was observed.

After making the necessary exclusions, six out of nine series remained to be analysed further. Series ID, date of establishment, date of mean maximum height, mean maximum height and growth period were the parameters used for data analysis (Table 6-2).

Table 6-2 Summary of series parameters

Series	Date Established	Date of mean maximum height	Mean maximum height [cm]	Max. reached day
3	4/12/2008	6/01/2009	6.041	33
4	21/12/2008	5/02/2009	2.849	44
5	8/1/2009	20/02/2009	3.182	43
6	27/01/2009	1/03/2009	2.293	33
7	14/02/2009	19/03/2009	2.246	33
8	03/03/2009	21/03/2009	1.324	18

The next step of the analysis involved plotting the maximum standing heights of each series against the date at which it was established. A linear regression of the data points showed a significant decrease of maximum standing height with time over the dry season (Figure 6-8).

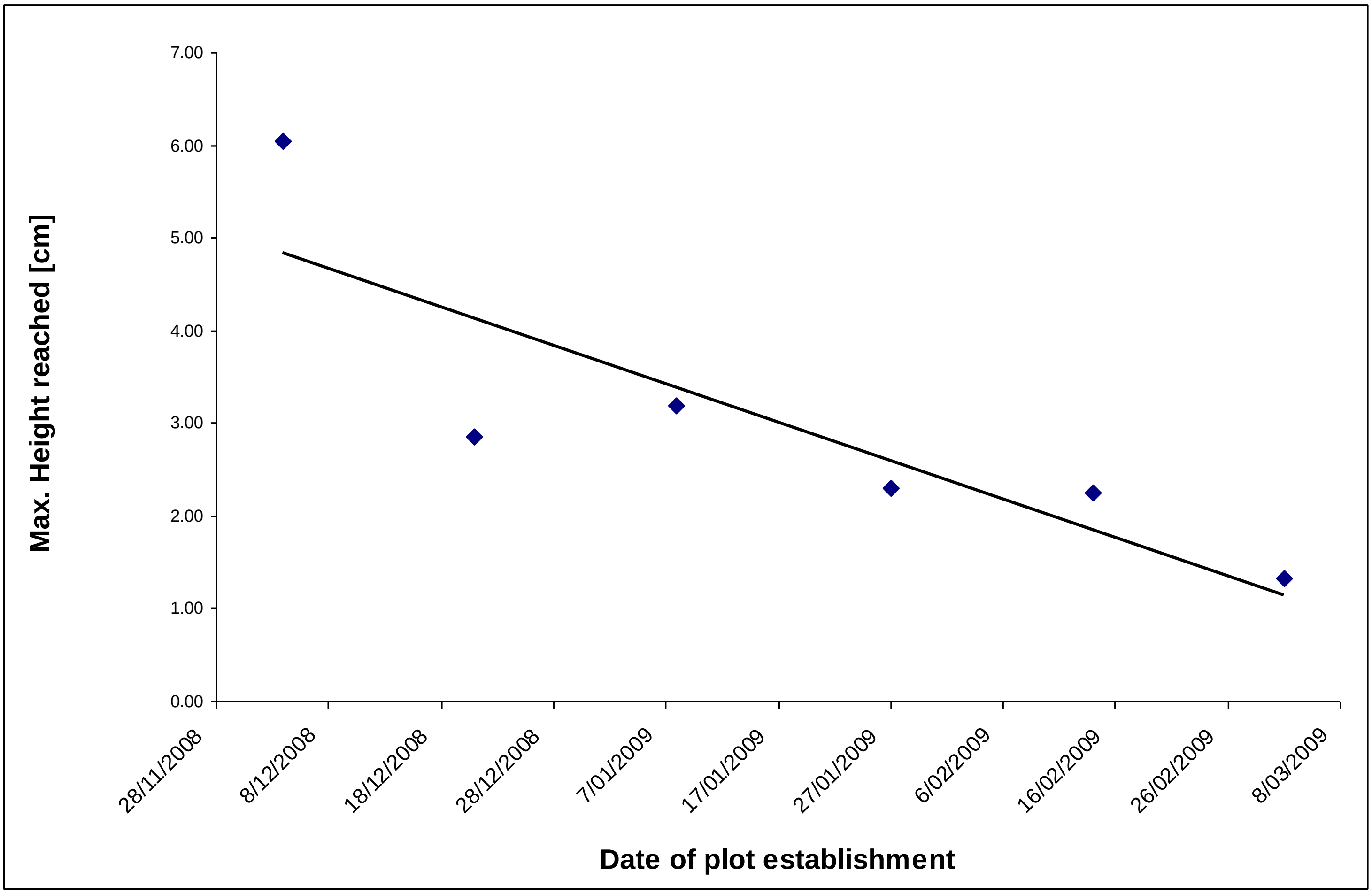

Figure 6-8: Linear regression of maximum standing heights over time (y = - 0.0415x + b).

An average decline in grass productivity during the dry season of 0.42mm/day for the Mambilla grasslands was calculated from the slope of the linear regression function (Figure 6-8).

When examining the growth pattern more closely, an interesting feature can be observed in addition to the general trend of lowered productivity (Figure 6-9). Firstly, in the first few months of they dry season, the active growth period lengthened (accompanied with a decline in productivity). This was followed by a shortening of the growth period and a concomitantly declining productivity after the beginning of January.

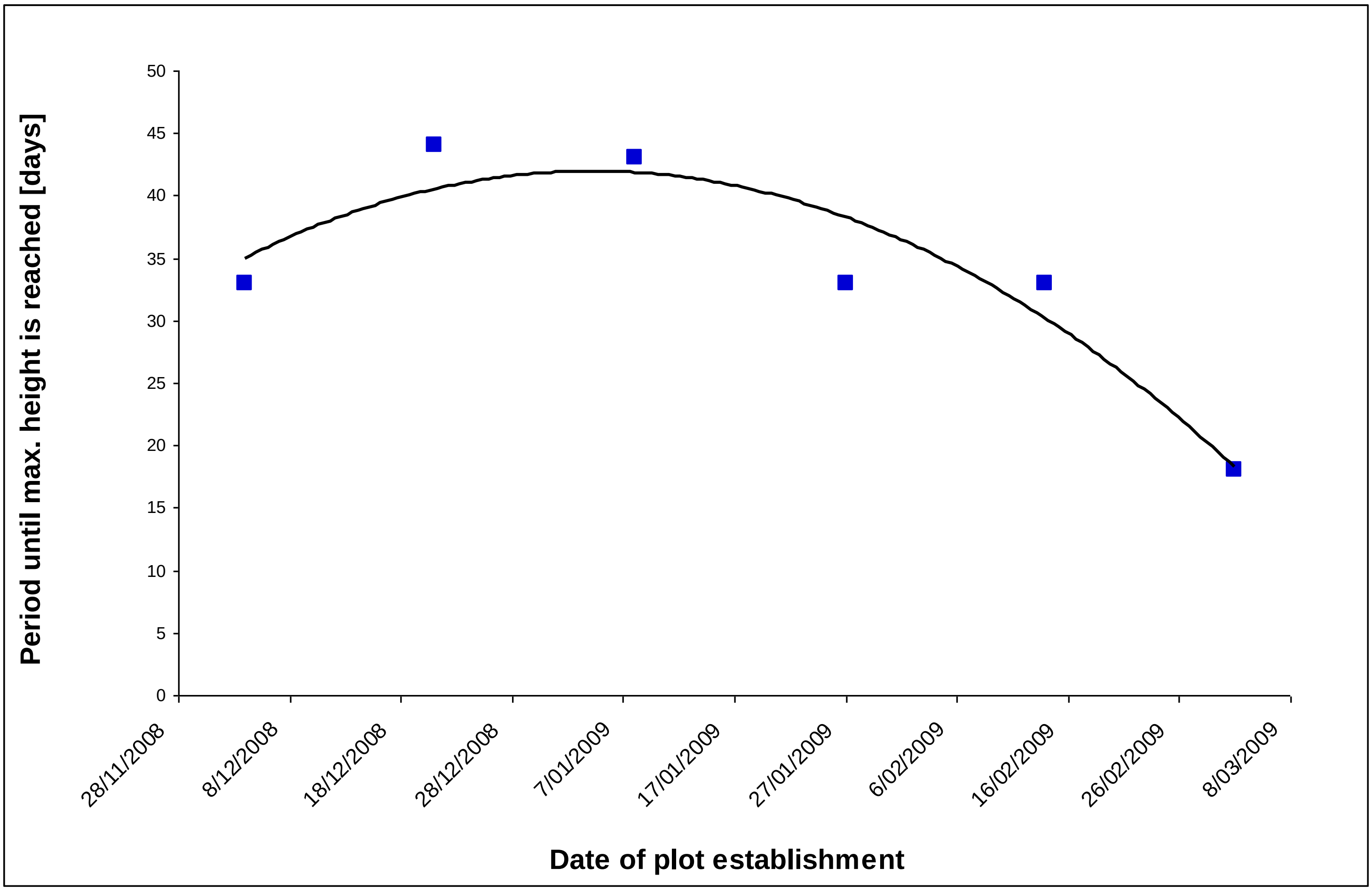

Figure 6-9: Relationship between time of plot establishment and time period until maximum height realisation

6.1.6 Discussion

The method with which the grass productivity was measured takes into account only the vegetative growth; rhizomic growth and growth from seed was not assessed. This should not be a significant limitation, however, because it was visually confirmed that intravaginal tillering is the dominant means of aboveground growth during the dry season.

The study focused only on the productivity of *Sporobolus spp.* as these grasses make up the bulk of cattle diet. In addition, these species comprise >90% of plant biomass in these grasslands. Between *Sporobolus spp*. tussocks other grass and herbaceous species can be found that may be important for cattle nutrition and may show very different growth patterns in response to drought.

In addition, this study may overestimate productivity as only living tillers were measured. It was observed that as the dry season advanced, a decreasing fraction of tillers were alive. Therefore the given decline in productivity reflects well the decline in productivity in live tillers, but ignores the increasing percentage of senescent tillers within each plot.

The results of the experiment are congruent with the general conclusion found in the scientific literature concerning grass productivity in other similar study sites, namely that grass productivity declines linearly with decreasing precipitation. However, it is not precipitation per se that drives the decline in grass productivity, but declining soil moisture levels resulting from the absence of rain (Belsky 1994; Epstein, Lauenroth & Burke 1997; Fay *et al.* 2000; Oesterheld *et al.* 2001; Nippert, Knapp & Briggs 2006; Swemmer, Knapp & Snyman 2007; Yang *et al.* 2008). Due to the strong growth responses after precipitation it can be assumed that in this grassland water is the major limiting factor at this time of year.

As the *Sporobolus* grasses on the Mambilla Plateau demonstrate a reduction in leaf growth and partial aerial senescence but not complete cessation of growth indicate that species in this genus are incompletely dormant during the dry season. The observation that an unseasonal rainfall event was able to induce vivid growth also signifies that *Sporobolus* was not dormant one month into the dry season (Volaire *et al.* 2009).

In interviews, pastoralists have noted that their main concern in the dry season is the decline in productivity and the resulting shortage of nutritious green forage. From these interviews it was also found that there are several different management strategies to meet the problem of declining productivity. First, the majority of cattle are moved off the plateau to the lowlands (destocking). This strategy allows the Fulani to maximize herd size, as in the more productive wet season a large number of cattle can be fed on a relatively small area and during the less productive dry season, these large herds can usually survive by utilizing a larger area (incorporating lowland areas in addition to the plateau) for grazing. During the dry season some herders who live in fixed abodes on their employers land during the wet season become transhumant. Second, the Fulani herders burn patches of senescent grassland to encourage the development of green flushes of nutritious forage for their cattle (burning). However, the energy requirements of the cattle are too high to limit feeding only to the new growth, so herders take the cattle to fresh regrowth in the mornings and then on to feed on senescent grasses in the afternoon. In contrast to the first strategy, the second one focuses more on maintaining good animal health over a difficult period than maximizing herd size per se (although in the end, lowering cattle mortality also leads to increased numbers). This supports the findings of Wilsey (1996) that ungulates with higher body mass need to feed on a range of different grass species and growth stages to meet their nutritional and energy needs. Interviews and observations both revealed that herders enrich their herds' nutrition by feeding them salt 1-2 times a month.

A third strategy employed by herders to meet the forage demand, especially in the early dry season, is to send the cattle into the Forest Reserve, where the tree rich savannah provides green forage for longer into the dry season than the grassland. The effects of trees on grass productivity are complex, but in some circumstances, facilitative effects can outweigh competition between trees and grasses in savannahs and thus lead to a higher productivity than grasslands without trees (Belsky *et al.* 1989; Scholes 1990; Belsky *et al.* 1993; Belsky 1994; Scholes & Archer 1997; Rhoades, Eckert & Coleman 1998; Ludwig *et al.* 2001; Ludwig *et al.* 2003). One Fulani informant said that they could only burn a certain amount of their land to promote regrowth, because if they burn too much, there is not enough forage on the pasture to meet the cattle's energy demand, but if they burn too little, the cattle are threatened by malnutrition. By grazing and burning additional land inside the reserve, they increase the limiting factor (land area) and are then able to keep more cattle on the plateau. This is an important driver for the cattle owner considering that migrating requires grazing rights to be procured at the destination, the inherent risk of injury to the cattle on migration, an increased risk of theft, and the increased risk of illnesses, which are especially prevalent in the lowlands at the beginning of the wet season.

6.1.7 Conclusion

The maximum standing height and new growth of grasses of the Mambilla Plateau rangelands declines over the course of the dry season, thus limiting the availability of cattle feed. The results of this experiment give some idea of the speed at which grass growth declines after termination of the wet season. As the herders are hard pressed to find enough forage for their animals on the plateau during the dry season, they adopt one or a combination of several strategies. One strategy they adopt is the pushing of cattle into the northern part of the reserve, where the partly shaded savannah provides fresh nutritious forage for longer into the dry season. With the advancing dry season the pastures on the plateau are also de-stocked with herds being transferred to the lowland where the Tsetse fly prohibits grazing during wetter parts of the year. This also is a good strategy for herd survival given the decline in grass productivity on the plateau and the prospect of recovered forage stocks in the lowlands.

Another implication derived directly from this data is that the more time passes before the grass is burnt, the shorter the maximum standing height that will be realised. Therefore, if burning is used as a management strategy, very early burning is paramount to maximise bulk forage availability. In addition, as can be seen from the second part of the analysis, the time until maximum height is realised first increases and subsequently decreases quickly with time. This means senescence sets in increasingly quickly with the advancing dry season. Therefore, in order to continuously provide cattle with nutritious forage through regular burning, the patches burnt should correspond to the amount of forage the cattle are able to graze within a shortening time frame. In practice this would usually mean repeated downscaling of burn-patch sizes from January onward through the remaining dry season as the longevity of green flushes rapidly decreases from this point in time.

6.2 Stream Flow

6.2.1 Introduction

Water and available forage are the main controllers of grazing (as established in section 6.1). Therefore water availability on Fulani held lands could potentially influence the herders' need to utilize the reserve. As interviews revealed most herders presently had enough water available outside the reserve to meet their cattle's needs, the research focused on the influence of streamside forest clearing (an ongoing practice in the region) on water availability. The information collected was aimed at predicting water shortages to occur in the future as a result of riverine forest clearance. If flow decreases with clear-cutting, the Fulani may inadvertently be creating a scenario where they face insufficient water supply on their lands and will therefore be increasingly dependent on illegally watering their livestock in the reserve in the future. If clear-cutting increases streamflow, the Fulani will most likely stay independent from water resources in the reserve (although the ecological tragedy of vanishing endemic riverine tree species is not lessened (Naiman and & Decamps 1997)).

Numerous paired watershed and vegetation manipulation (deforestation/ afforestation) studies have demonstrated that deforestation of watersheds leads to higher annual water yields downstream and afforestation leads to reductions in both peak and base flows (Bosch & Hewlett 1982; Calder 2002; Bruijnzeel 2004). This would disqualify the commonly held view that forests act like sponges, which soak up water during precipitation events (preventing floods) and release water to provide a stable supply during dry spells (Bartarya & Valdiya 1989; Bruijnzeel 2004; FAO 2005; Gyenge, Fernandez & Schlichter 2009; Little *et al.* 2009).

However, some studies have found increases in annual water yield when afforestation was carried out (1) in large scale watersheds (~10,000ha) (Little *et al.* 2009) or (2) with native tree species (Lara *et al.* 2009). The differences between results of scientific experiments (increase in base flow) and frequently publicly observed effects of deforestation (decrease of base flow) can be largely attributed to land management after conversion in areas of seasonal rainfall (Bruijnzeel 2004). Frequently, land use changes in ways that considerably reduces the infiltration capabilities of the soil (overgrazing, urbanisation, soil compaction by farming). This leads to a much increased run-off during the rainy season and reduced groundwater recharge. Thus, while in the short term, base flows may increase, in the long run, they may well decrease through a drop of the groundwater table (Bruijnzeel 2004; Little *et al.* 2009). The argument explaining base flow increase after afforestation with native trees, is that native trees are adapted to local conditions, are often slower growing and have lower evapotranspiration rates than fast growing exotics (Lara *et al.* 2009). Therefore, when trying to predict the water availability in a stream at a given locale it is important to understand the interactions of precipitation, vegetation and land use on the different hydrological variables that effect streamflow.

Other possible adverse effects of deforestation like flooding and erosion (Calder & Aylward 2006; Bradshaw 2007; van Dijk *et al.* 2009) are acknowledged, however, as the focus of this study lies with low flows they wo not be addressed in any great detail.

6.2.1.1 Stream hydrology

Streamflow can be separated into two distinct types: peak flow and base flow. Peak flow is the maximum swelling of a stream shortly after a precipitation event. Base flow is the minimum flow experienced by a stream in the absence of rainfall and is solely fed from the groundwater table (Gordon *et al.* 2004).

Peak flow can have several sources: surface flow (also known as overland flow), subsurface flow and base flow all contribute to peak flow. Surface flow is generated when the precipitation rate exceeds the infiltration rate and is the main cause of water erosion on the land surface (Figure 6-10). Subsurface flow (also known as interflow) often occurs when rain falls on a sloping surface, with the water infiltrating the upper soil layers but deep percolation is prevented by an impermeable soil layer or bedrock and thus water flows down slope within the soil matrix (Gordon *et al.* 2004).

The groundwater table, which affects base and peak flows, is recharged by deep percolation during rain events (Gordon *et al.* 2004). Compared to bare soil, vegetated surfaces usually have a higher water infiltration rate. Therefore the presence of vegetation supports subsurface flow and groundwater recharge and reduces surface flow (Bharati *et al.* 2002).

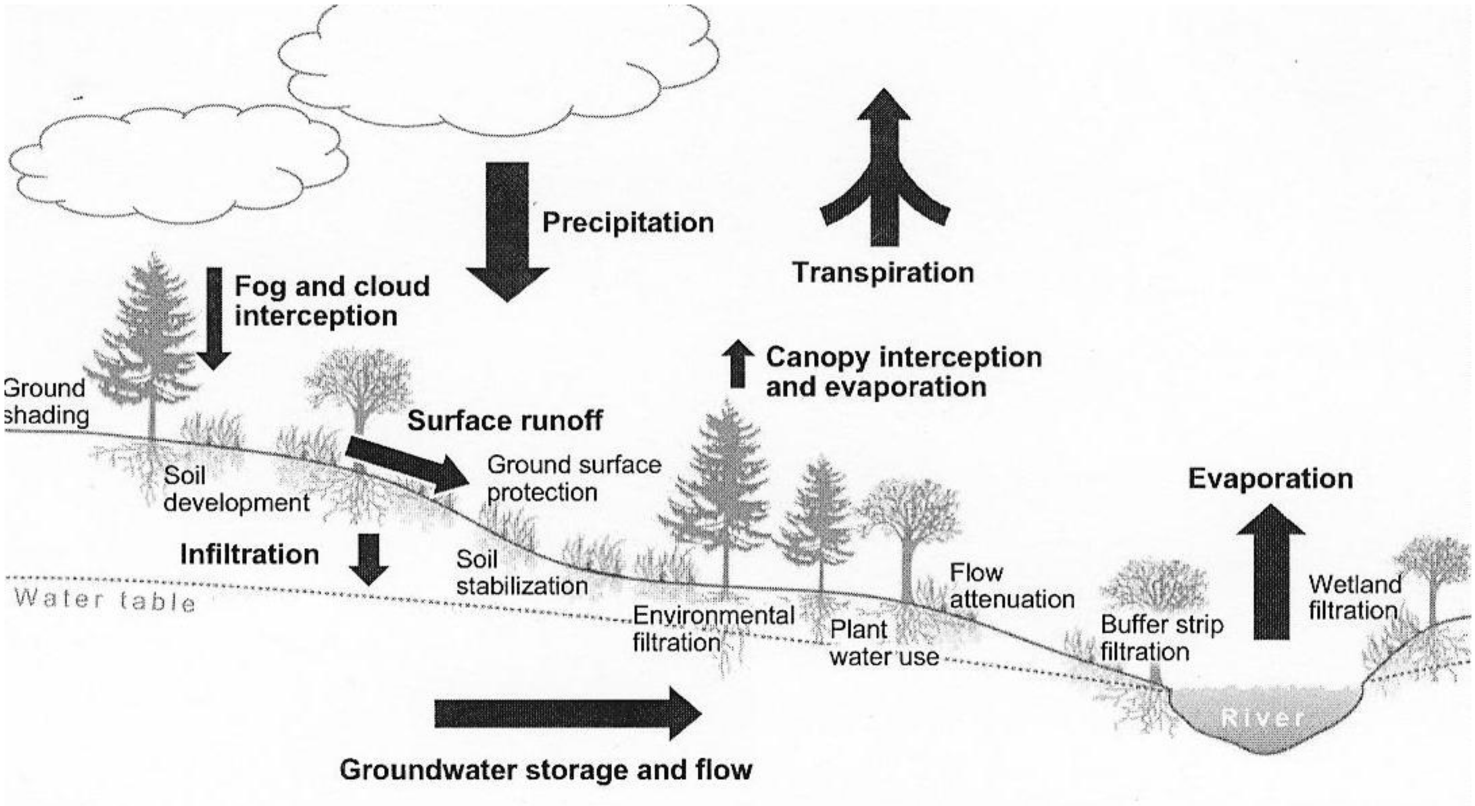

Figure 6-10: Summary of environmental factors affecting streamflow (Brauman *et al.* 2007)

The main focus of this chapter is the effect of vegetation on low flow rates. As has been noted earlier, the common myth sees forests as "producers" of water rather than consumers (FAO 2005). The "sponge" hypothesis is one way by which forests are supposed to modulate streamflow while another is the creation of clouds attracting precipitation (Meher-Homji 1991). Scientific research has found the latter to be true only on large scales although the matter is not entirely settled and probably depends very much on the locale (van Dijk & Keenan 2007). Elements of truth have been found in the former myth, but the reality is much more complex than the myth. Scientific research has found that many of the involved variables are interlinked and can change seasonally, spatially and temporally (Bruijnzeel 2004; Brown *et al.* 2005). The interconnectedness and multiplicity of involved variables substantially complicate the creation of a mechanistic model of vegetation changes on flow and makes sustainable watershed management a very difficult and contested subject (FAO 2005; van Dijk *et al.* 2009). Factors affecting mean, peak and minimum flows include plant species present in the watershed, density and age of the vegetation, total precipitation, precipitation variability, soil condition, shading, geology and slope (Bruijnzeel 2004). With this variety of variables, reliable predictions about the effects of land use changes in watersheds on stream flow in a specific locale are very difficult to make. Nevertheless, predictions are essential to guide effective land management, as mismanagement can potentially have catastrophic results (flood or drought). To clarify the effects of the main variables, they have been reviewed in the following sections.

6.2.1.2 Geology and topography

Peak streamflow is sensitive to precipitation. The particular way in which peak flow is affected by rainfall is determined to a great extent by the topography of the landscape. For example, steeper slopes in headwaters lead to faster streamflow responses and higher flow peaks because of higher run-off speeds.

Base flow on the other hand is largely dependent on stream interception of the groundwater table and hence for base flow, the geology plays a more important part. For example, stream reaches lying above the water table that have a porous underlying geology are losing water to the groundwater while stream reaches that continually intercept the water table are gaining flow with stream length.

Local geology and topography also have significant effects on ground water recharge, which affects the depth of the groundwater table and in turn peak and base flow (although to different degrees) (Gordon *et al.* 2004).

Nested within these physical constraints, vegetation in watersheds has the power to considerably changes streamflow patterns.

6.2.1.3 Environmental factors affecting baseflow

6.2.1.3.1 Effects of land cover on base flow

When considering land cover effects on base flow, the ground surface is most commonly separated into one of three classes: bare soil, grass and woody vegetation. As has been described in the introduction, depending on the geology and soil particle size, bare soil has the smallest water infiltration rate (exception: gravel and sand), grassland a medium infiltration rate and forests the highest. Correspondingly, bare soil has the highest run-off and erosion rates of the three classes, especially when soil is compacted. Depending on ground cover and other factors like grass phenology, grassland and forest can have similar erosion and run-off rates, but usually forested areas show lesser rates of both (Monteith, Ong & Corlett 1991; Kiepe 1995; Sanchez 1995; Ong & Leakey 1999). This leads to the conclusion that there is more water available for base flow in forested regions than in areas with bare soil. Vegetation, however, also evaporates large quantities of water through the stomatal openings of the leaves, especially in hot and dry weather, which constitutes a negative effect of vegetation on base flow that also needs to be considered (Jackson & Wallace 1999).

6.2.1.3.2 Effects of growth pace

Gas exchange through stomatal openings is necessary for growth as the CO_2 in the air is the main carbon source for plants. With an increased growth rate, more gas exchange is needed, stomatal resistance is lower and hence more water is transpired (Franks & Farquhar 2007). Fast growing trees usually display greater transpiration and require larger quantities of water than slow growing trees. Therefore, if a watershed forested with a slow growing tree species is logged and reafforested with a fast growing tree species (like some spruce, pine or eucalyptus species) a reduced base flow is expected (Gyenge, Fernandez & Schlichter 2009).

An experiment conducted by Swank *et al.* (1988) confirmed differences in evapotransipration between fast and slow growing species as well as between small and tall growing vegetation. They found that conversion of native hardwood forest to pine plantation led to a decline in annual stream discharge. The opposite could be observed by conversion of native hardwood forest to grassland. The conclusions drawn from this study were that fast growing pine trees use considerably more water than native hardwood trees and that native hardwood trees use slightly more water than native grassland.

6.2.1.3.3 Effects of water stress

When comparing different species and their potential effect on baseflow, it needs to be noted that transpiration is usually only limited when water stress is experienced. Therefore, access to water is the critical factor affecting transpiration rate. Generally, deeper rooting plants will experience water stress later during a dry spell and will therefore reduce their transpiration rate later as well (Tanaka *et al.* 2004). Vegetation close to perennial streams can be expected to have higher transpiration rates because the roots of such vegetation may easily penetrate the permanently moist soil along the riverbed and will not experience water stress, even during dry spells (Gazal *et al.* 2006).

The often quoted higher evapotransipration rate in forests than in grasslands can therefore be explained by the relative greater rooting depths of trees and the relative higher rainfall interception by the forest canopy (Calder 2004). Even during dry seasons when rainfall interception effects are not relevant due to an absence of rain, and the groundwater level is close to the surface (as in riparian zones) trees still continue to display higher evapotransipration rates than grasses (Williams *et al.* 2006).

6.2.1.3.4 Effects of vegetation age and density

The scenario where an old growth forest is replaced by secondary forest in a watershed can have similar effects on base flow as when slow growing species are replaced by fast growing species. The water requirements of a young forest have been shown to be proportional to the total basal area of the woody vegetation. Old growth forests, on the other hand, show a more conservative draw on water resources per basal area. This, in conjunction with the reduced density of trees in old growth forest makes for much reduced water requirements in an old growth forest, compared with a young forest (Calder 2002; Moore *et al.* 2004).

Giambelluca (2002) demonstrates that the density and patchiness of forest clearing also has a significant impact on evapotransipration and hence, streamflow. It was concluded that increased wind invasion is responsible for higher evapotransipration rates in fragmented forests compared with a single, unfragmented forest of the same size.

6.2.1.3.5 Shading

As explained above, the type of vegetation present in a watershed has a significant impact on streamflow. Evapotranspiratory differences account for most of the effects on streamflow, nevertheless shading can also constitute an important factor that may affect water balance positively, especially in arid or seasonally arid environments. Shading may aid in the conservation of soil moisture in regions of high solar irradiance (Wilcox 2002). Microclimatic effects of vegetation (such as higher below-canopy air moisture levels, lower radiation, lower temperatures and lower wind speeds) may also indirectly affect streamflow through lower transpiration demands in shaded plants (Holmgren, Scheffer & Huston 1997).

6.2.2 Study site

The streams, or stream reaches measured in this study were all located on Fulani properties immediately outside the Ngel Nyaki and Kurmin Danko Forest Reserves (Figure 6-11). All streams had watersheds that were intensively used for grazing and were not forested, except in the immediate proximity of the stream. The forest cover in the riverine buffer varied from heavily forested to almost bare of tree cover. Where forest vegetation was missing, either shrubby vegetation or grassland was apparent.

The watersheds were mostly covered by grassland. In some cases large areas of these grasslands were burnt. There were no agricultural fields upstream from the measuring plots that could influence streamflow by diverting water for irrigation.

The streams were all relatively small with flow rates equal to or below 0.025 cumecs at the beginning of the dry season. Most streams had rocky beds with varying sizes of gravel and stones while a few had muddy beds. The measured streams also varied in average downward gradient from a relatively flat ~5% (~2.9 deg.) to a very steep ~25% (~14 deg.)[21].

Although an attempt was made to select streams with uniform characteristics except the target variable (e.g. riverine vegetation cover) across the whole sample, this was not entirely possible as limited mobility restricted the choice of streams to those that were reachable by foot from the NMFP field station within a reasonable period of time.

[21]This was measured using a digital elevation model (see chapter 3)

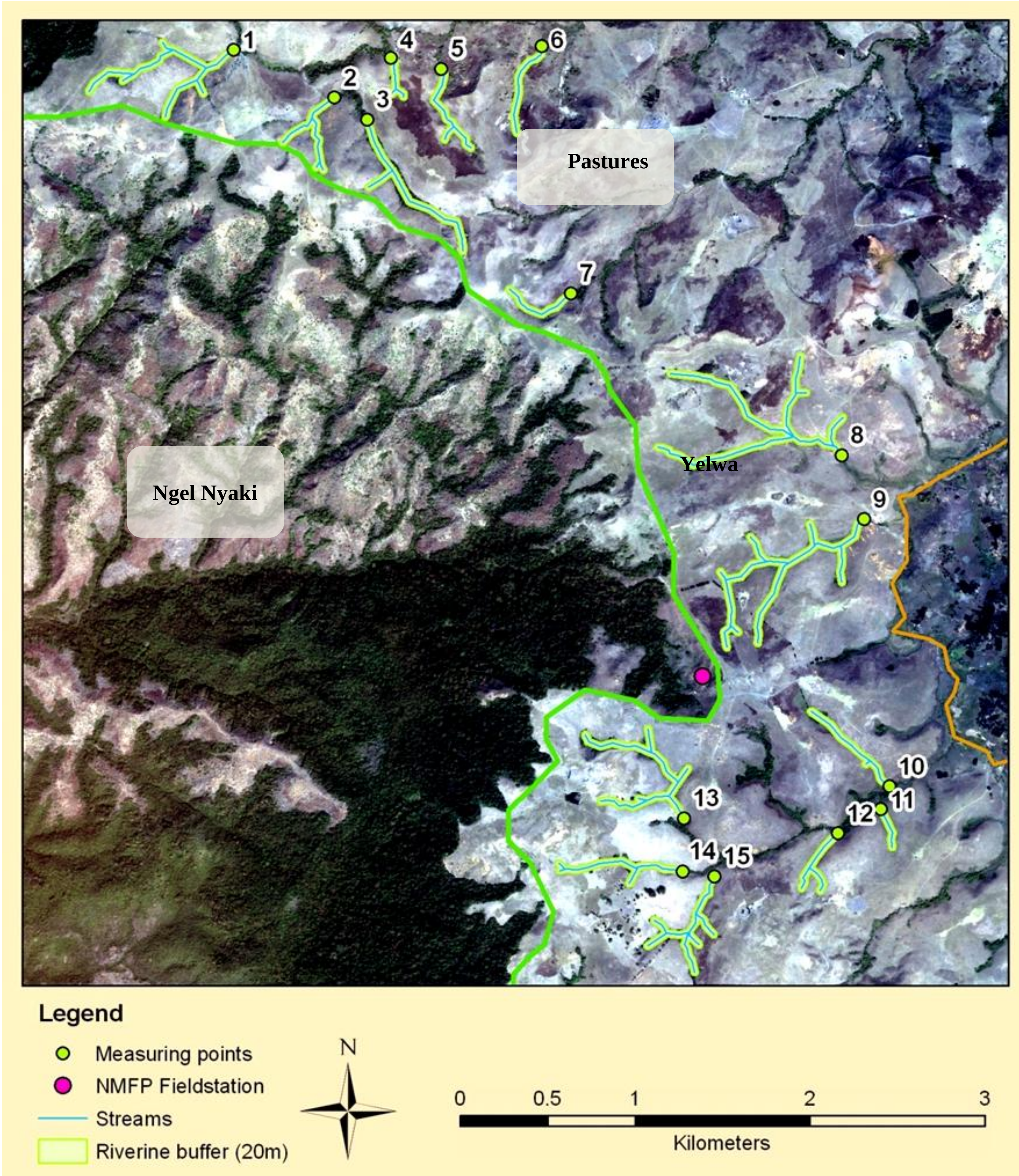

Figure 6-11: Locations of measured streams in the study area

6.2.3 Purpose of study

Different climatic areas require management and prediction of different aspects of streamflow. While flood prone areas may be more concerned with peak flows, management in arid and seasonally arid climates will concentrate more on minimal flow. In regions with extended dry periods, such as the Mambilla Plateau (see chapter 2.1.3) the basal flow rate of streams is vital to the survival of livestock and the human population during the dry season. Therefore, every action that could threaten the persistence of perennial streams has to be thoroughly evaluated. The last century has seen rampant deforestation of the plateau's watersheds and riverine buffer vegetation. Most deforestation has occurred due to cattle trampling, firewood collection, timber harvest for construction, swidden agriculture or pasture expansion through burning (Chapman, pers. comm.). In recent years the cutting of native trees has slowed and the need for firewood and wood for construction has been met through government and privately owned plantations of *Eucalyptus* (MacDonald 2007; Korndoerfer 2010; pers. obs.). However, the remaining riverine forests on privately held land are not under total protection and landowners may purchase the right to clear individual trees from the local government authority. This is quite a common practice and on many rangelands amidst the last remaining forest stands of a stream headwater freshly felled trees can be seen (pers. obs.).

As the raising of cattle is dependent on both, the availability of forage and of water, the question is raised whether the Fulani are increasing or decreasing minimum flow during the dry season by their practice of clear-cutting riverine vegetation. Stream banks have significant importance for crop cultivation, but also for grazing, as here the grasses stay green and nutritious for longer into the dry season, sometimes remaining green throughout the whole period.

Most studies reporting vegetation effects on base flow focus on watershed de- or afforestation. This study, however, looks only at the effects that clearing of riverine forests have in an area where watersheds are largely deforested already. Trees in riverine buffer zones have good access to moisture and are therefore expected to exhibit high evapotranspiration rates throughout the dry season. Hence, it could be expected that clearing these forests leads to a significant increase in dry season flow. Alternatively, given Nigeria’s tropical locale and hence high solar irradiation and high temperatures, riverine forests may help conserve water by shading and reducing ambient temperature and wind speeds in the riverine zone.

This question potentially has a great influence on the future relationship between the pastoralists and the reserve as well as the future of total cattle carrying capacity in the area.

This chapter therefore investigates the effects of streambank vegetation cover type (forest or grassland) and the drop in basal streamflow in 15 streams during the 2008/2009 dry season.

6.2.4 Aims and Goals

This chapter investigates whether the level of riverine forestation affects base flow during the dry season in streams on Fulani land in the vicinity of Ngel Nyaki Forest Reserve.

6.2.5 Methods

6.2.5.1 Determining levels of riverine degradation and choosing streams

6.2.5.1.1 Visual classification

An initial survey of streams was undertaken and the quality of streamside forests visually classified as either A (intact), B (semi-degraded) and C (very degraded). Intact forest was defined as riverine forest with a closed canopy and more than one row of trees on each stream bank. Semi-degraded riverine forest was defined as open canopy or only one row of trees along each stream bank. Streams falling into the 'very degraded' stream class had predominantly grassy stream banks with only small patches of trees or shrubs along its extent. It was attempted to have 5 streams in each degradation class in order to have enough replicates for statistical analysis. However, as detailed analyses of actual tree cover later revealed this was not entirely achieved.

In order to reduce confounding effects of differing forest qualities along a stream reach, streamflow measuring plots were established in positions where the upstream riverine forest was as uniform as possible and representative of the stream's forest quality classification.

6.2.5.1.2 Transects for DBH measurement and tree count

As previous studies have shown strong relationships between forest basal area and streamflow (Stednick 1996; Lane & Mackay 2001), 40 m long transects, 3 m wide, were laid out perpendicular to the stream reach across the stream buffer (Figure 6-12). The first transect was placed at the gauging site and further transects placed every 100 m upstream from there. When the stream branched, transects were continued up both arms of the stream, with the first transect of each arm being placed 100 m upstream from the last transect downstream of the two arms' intersection. Where the stream reach ended before a full 100 m distance could be measured no transect was put in place. The 100 m distances were measured and recorded with a Garmin GPS unit. Within each transect all trees with diameter at breast height (DBH) greater than 5 centimetres were measured.

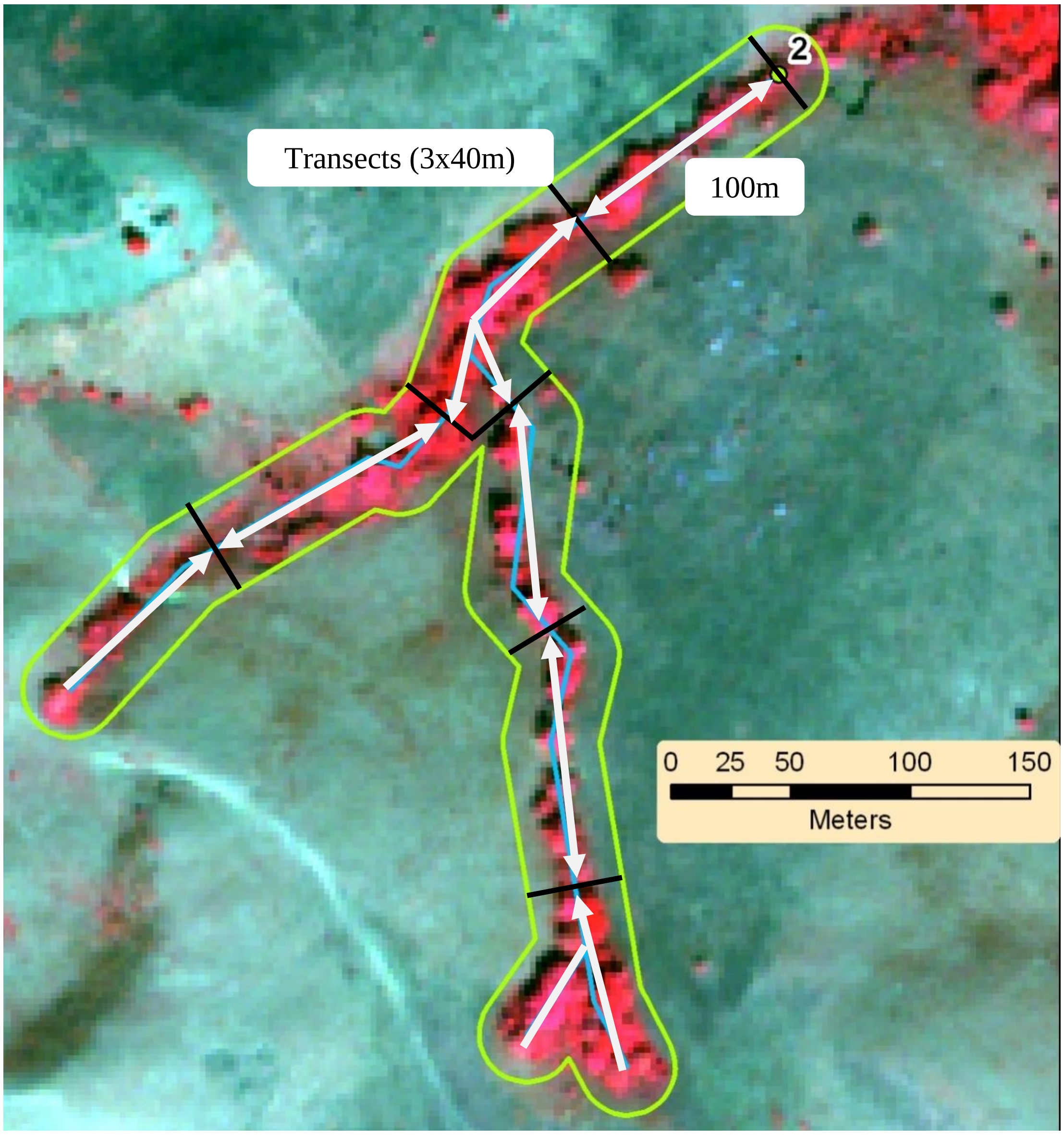

Figure 6-12: Example of transect establishment

The ratio of total sampled DBHs / buffer area was calculated for each stream. This was intended to be used as a basis to separate streams into classes of intact, semi-degraded and very degraded riparian forest.

6.2.5.1.3 GIS analysis of stream vegetation

An analysis of the percentage of tree cover was carried out using high resolution satellite imagery (QuickBird). A multi-spectral (red, blue, green, near infra-red) image was used to classify the vegetation into grassland or forest (see chapter 3 for details). A buffer of 20 m was then created on both sides of the digitised streams. The ratio of as forest classified pixels to total pixels within the buffer area was used as a measurement of tree cover for each stream. This was intended as verification for the stream classes defined by average DBH/ha in the section above.

6.2.5.2 Watershed sizes and stream length

In order to account for differences in base flow that could potentially be attributed to different watershed sizes or stream reach lengths (see section 6.2.1.2) instead of vegetation cover, these parameters had to be measured.

Watershed sizes and stream lengths were measured with ESRI's ArcGIS program (see chapter 3). First, a triangulated irregular network (TIN) of the surface area was created by digitizing the contour lines of a topographic map. Subsequently, the TIN was interpolated into a digital elevation model (DEM) with the inbuilt inverse distance weighting function. In the next step, a depressionless DEM was created from the first one with the fill sink function as the study area shows no natural sinks. After this process, the flow direction and flow accumulation maps were created. The calculated drainage pattern derived from the flow accumulation map was visually verified for congruency with actual stream locations. Finally, the total area draining through each gauging site were displayed and their sizes noted.

For stream length measurements, all perennial flow sections of the measured streams were first digitised with the help of high resolution satellite (QuickBird) imagery. The lengths of all reaches belonging to the same stream were then added up, giving the overall stream length (upstream from the measuring site) for each stream.

6.2.5.3 Stream flow measurement

Streamflow measurement was carried out as described in Gordon *et al.* (2004). Due to very limited resources and materials available in this remote location, the old fashioned method of measuring streamflow using a float was the only option available.

The streamflow measuring plot was defined by stringing out a start line and a finishing line. The distance between the two constituted the distance for the float experiment. The width and cross-sections of the stream were then measured along these lines. The depth was measured at five points evenly spaced across the width of the stream (see Figure 6-13).

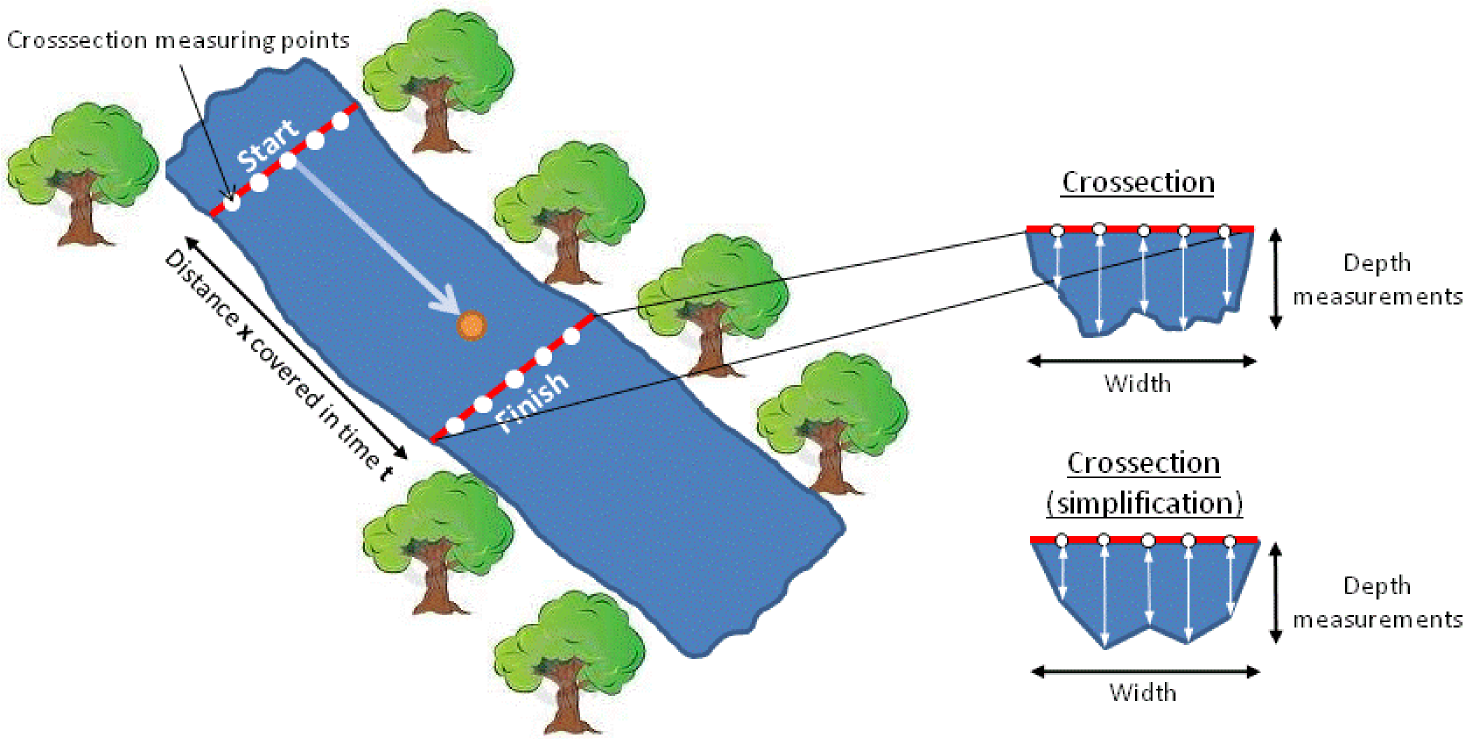

Figure 6-13: Idealised sketch of the streamflow measuring procedure

For the flow speed measurement a float, usually a piece of wood was thrown into the stream slightly upstream of the starting line to allow acceleration to flow speed. The time that it needed to move from the starting to the finishing line was recorded. The measurement was repeated five times and the average of the three fastest runs calculated. The rejection of the two slowest runs was considered sensible as often speeds showed high variability due to floats held back in eddies or moving into regions of stagnant water. The whole procedure was repeated every three weeks throughout the dry season for each of the 15 streams or until the stream had run dry.

6.2.5.4 Statistical analysis and base flow modelling

The statistical analyses of potential predictors of streamflow were carried out with the statistical program R (version 2.9.2). In particular, the packages lme4 and rattle were used for analysis. Lme4 was used to model the measured drop in streamflow over time in relation to forest cover as a linear mixed effects model. The rattle package was used to create regression trees that were used to identify the variables that present the best splitting factor to predict final days flow percentage.

6.2.6 Results

6.2.6.1 Stream characteristics

The first measurements were taken approximately one month into the dry season on 9 December 2008. Subsequent measurements were taken every 21 days thereafter. To compare the average drop in streamflow between streams, the measurements were normalised. The watershed size, stream length, buffer area, total tree count, total

DBH, forest cover (from satellite), average DBH/tree, average DBH/ha, average tree count/ha and the average stream gradient were calculated for each stream and tested for significance in predicting streamflow within a generalised linear mixed effects model. However, none of the land cover related variables had a significant effect. The only variable tested as being a significant predictor of streamflow was the stream gradient, which likely confounds the results.

Table 6-3: Characteristics of measured streams

Stream ID	Streamflow [dm^3/sec]				Normalised streamflow [% of first measurement]]				Watershed size [ha]	Reach length [m]	Average slope of stream [%]	Buffer area [ha]	Forest cover of buffer zone [%]	Average DBH/Tree [cm]	Average DBH [cm]/m^2	Average tree count/ha
	09/12/08	30/12/08	20/01/09	10/02/09	09/12/08	30/12/08	20/01/09	10/02/09								
1	5.9	1.4	0.8	0.0	100%	25%	14%	0%	52.4	1844	-12.3%	6.4	64%	36.3	1.08	328
2	1.5	0.6	0.1	0.0	100%	38%	10%	0%	19.3	1023	-11.9%	3.1	46%	22.4	0.40	179
3	5.7	4.1	2.6	2.1	100%	72%	45%	36%	32.7	1172	-8.0%	4.8	86%	17.4	1.21	1028
4	2.0	1.4	1.2	0.9	100%	74%	59%	44%	5.6	298	-21.1%	1.3	53%	49.2	0.82	167
5	3.6	3.1	2.3	1.2	100%	87%	63%	33%	21.7	657	-14.7%	2.7	39%	33.3	0.91	274
6	0.5	0.0	0.0	0.0	100%	0%	0%	0%	9.2	564	-25.7%	2.4	15%	12.8	0.23	181
7	1.5	0.7	0.6	0.2	100%	47%	37%	16%	12.6	459	-10.3%	1.9	58%	25.9	0.57	222
8	22.1	14.5	11.7	7.8	100%	66%	53%	35%	111.4	2931	-6.5%	10.9	34%	24.6	0.46	205
9	21.8	13.7	7.0	4.7	100%	63%	32%	22%	80.9	2492	-9.2%	9.9	44%	23.5	0.34	147
10	11.7	5.4	3.1	3.8	100%	46%	27%	33%	26.4	667	-5.6%	2.8	54%	23.9	0.44	190
11	7.6	4.4	2.7	2.2	100%	58%	36%	29%	8.0	239	-8.7%	1.1	63%	46.4	0.77	167
12	0.0	0.0	0.0	0.0	100%	0%	0%	0%	15.6	559	-14.6%	2.3	24%	31.8	0.18	71
13	25.7	16.1	8.0	5.5	100%	63%	31%	22%	48.9	1593	-10.6%	6.4	78%	20.2	1.17	667
14	5.7	3.0	1.5	0.5	100%	53%	26%	9%	29.8	847	-11.8%	3.6	65%	30.4	1.30	517
15	13.4	7.3	5.6	4.1	100%	55%	42%	30%	42.5	1261	-7.4%	4.9	65%	19.7	1.00	583

6.2.6.2 *Comparison of forest metrics*

The level of forestation along streams was measured in three different ways: (1) average DBH per ha (within the buffer area), (2) average tree count per ha (within the buffer area) and (3) percentage forest cover (within the buffer area) as derived from the classification results of the satellite image. In order to find out if these measures could be used interchangeably in future research design the three measures were compared to each other using the spearman's rank correlation coefficient (Table 6-4).

Table 6-4: Different measures of stream forest quality using spearman's rho

	DBH/m^2	Trees/ha	Percent forest cover
DBH/m^2	1		
Trees/ha	0.825	1	
Percent forest cover	0.836	0.732	1

The comparison shows good correlation between the three types of measurement. The remotely sensed measure of forest cover correlates the strongest with the measurement for DBH/m^2. There is also a strong correlation between DBH/m^2 and trees/ha. Although weaker, there is still a reasonable correlation between trees/ha and remotely sensed forest cover.

6.2.6.3 Decrease of flow during the dry season

Streamflow in all 15 measured streams dropped dramatically over the course of the dry season, with average flow across all streams 63 days after the initial measurements, being only ~20% of the initial flow (Figure 6-14).

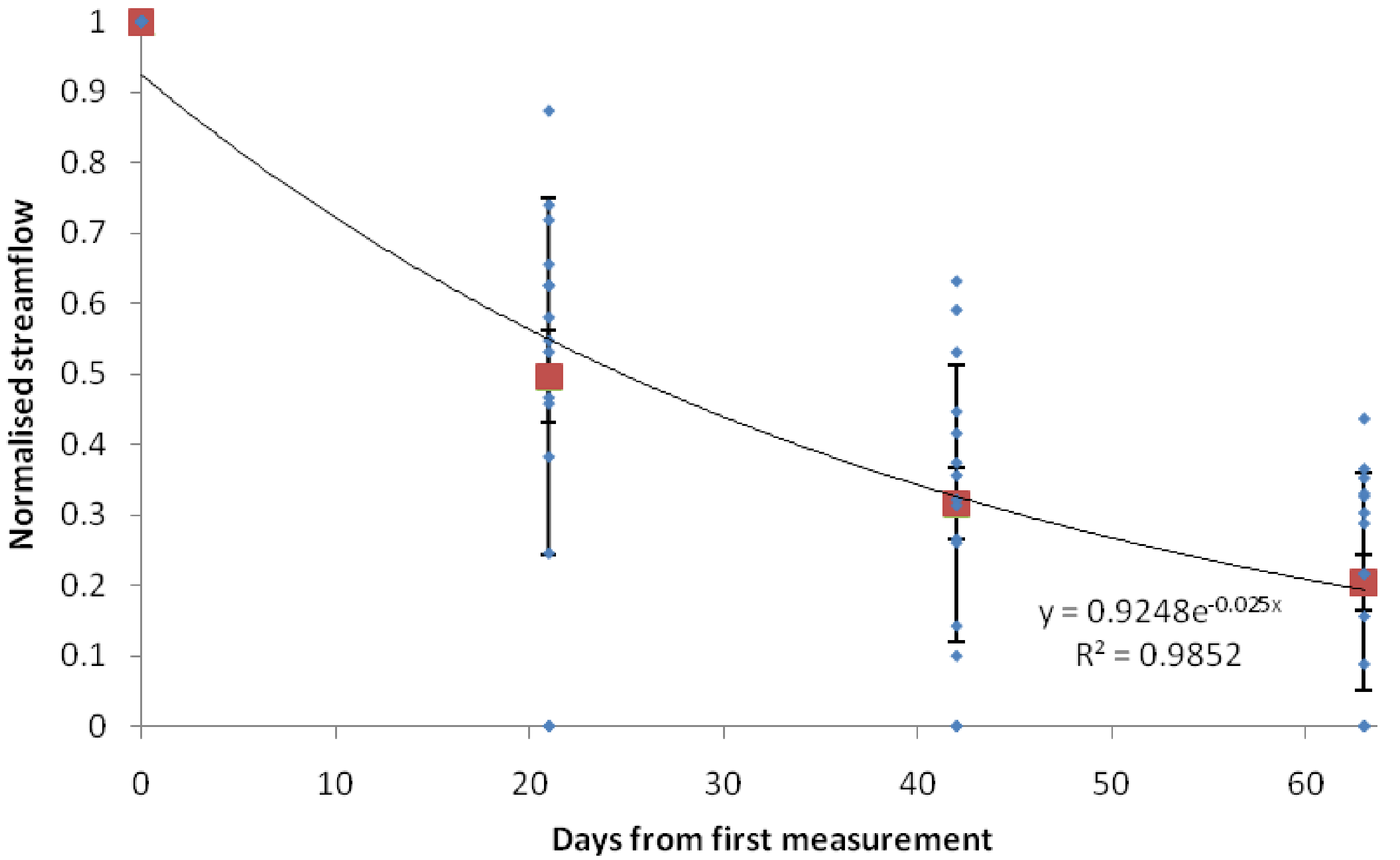

Figure 6-14: Decrease of streamflow over the dry season. The first measurement was made approximately one month into the dry season, with subsequent measurements every 21 days. The error bars represent one standard deviation of the mean.

6.2.6.4 Division of streams into groups

As no model was found that was able to predict streamflow in relation to riverine forest cover, a regression tree analysis was carried out to find out which of the measured variables are the most relevant for the grouping of streams (Figure 6-15). As the main question was whether riverine forest clearing leads to increased base flow in the study area only the last flow measurement of each stream was used in the regression as the target variable.

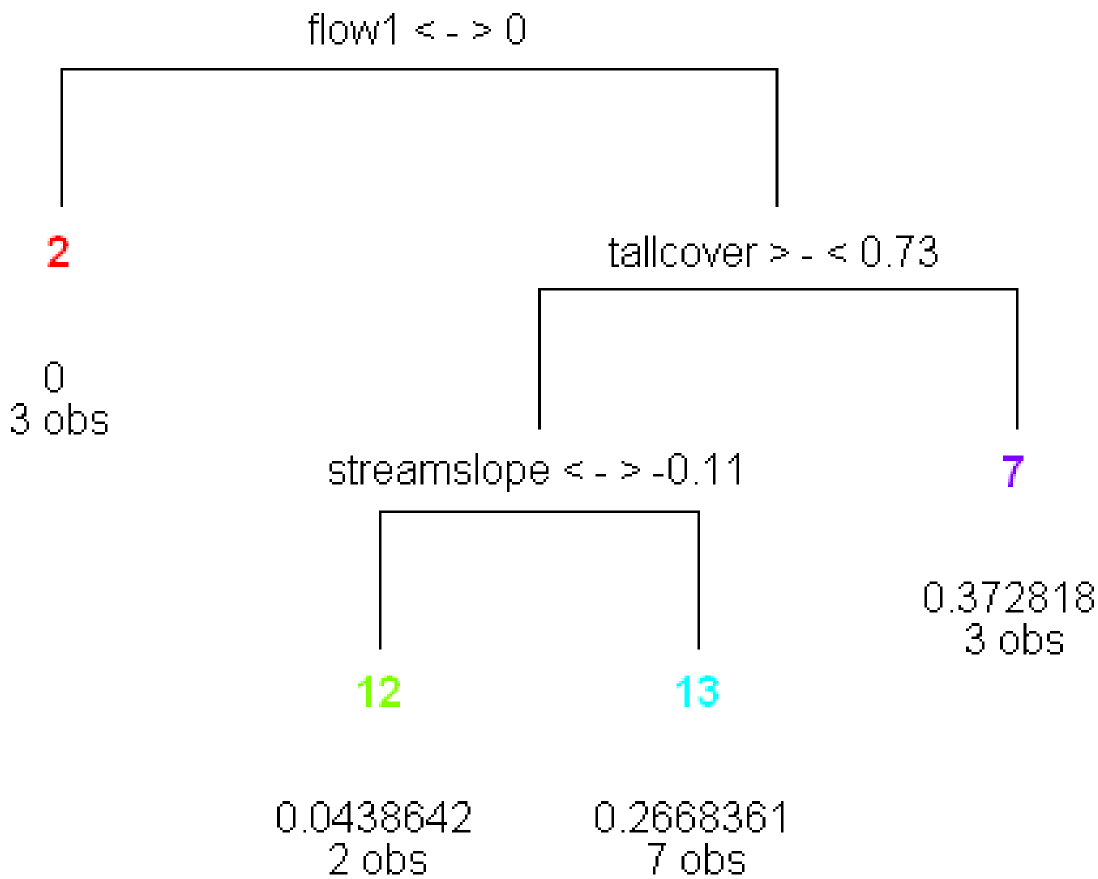

Figure 6-15: Regression tree of last days streamflow

From the regression tree analysis it can be deduced that the initial size of streams is the variable best suited to split the data set. For the three streams with the least flow no other variables were suitable to split these streams into further groups (node 2). For streams with higher flow, the variable performing best on splitting the remaining 12 streams is tall cover. Tall cover includes the forest class and the long grasses and scrubland class as defined in chapter 3. There are three streams in the higher streamflow / lower tall cover group (node 7), while nine streams are in the higher streamflow / higher tall cover group. Further analysis revealed that the parameter describing the average physical gradient of the stream ("streamslope") could split the latter group further into a high gradient and a low gradient group. However, because of the limited size of the dataset, these streams were not separated out further for the subsequent modelling of the different groups.

6.2.6.5 Modelling of the low flow group

The three streams of the low flow group, demonstrate a very steep drop between the first and the second measurement (Figure 6-16). Two of the steams had already dropped to zero flow by the time of the second measurement. At the third measurement, the remaining stream showed very little flow and flow had stopped completely by the fourth measurement.

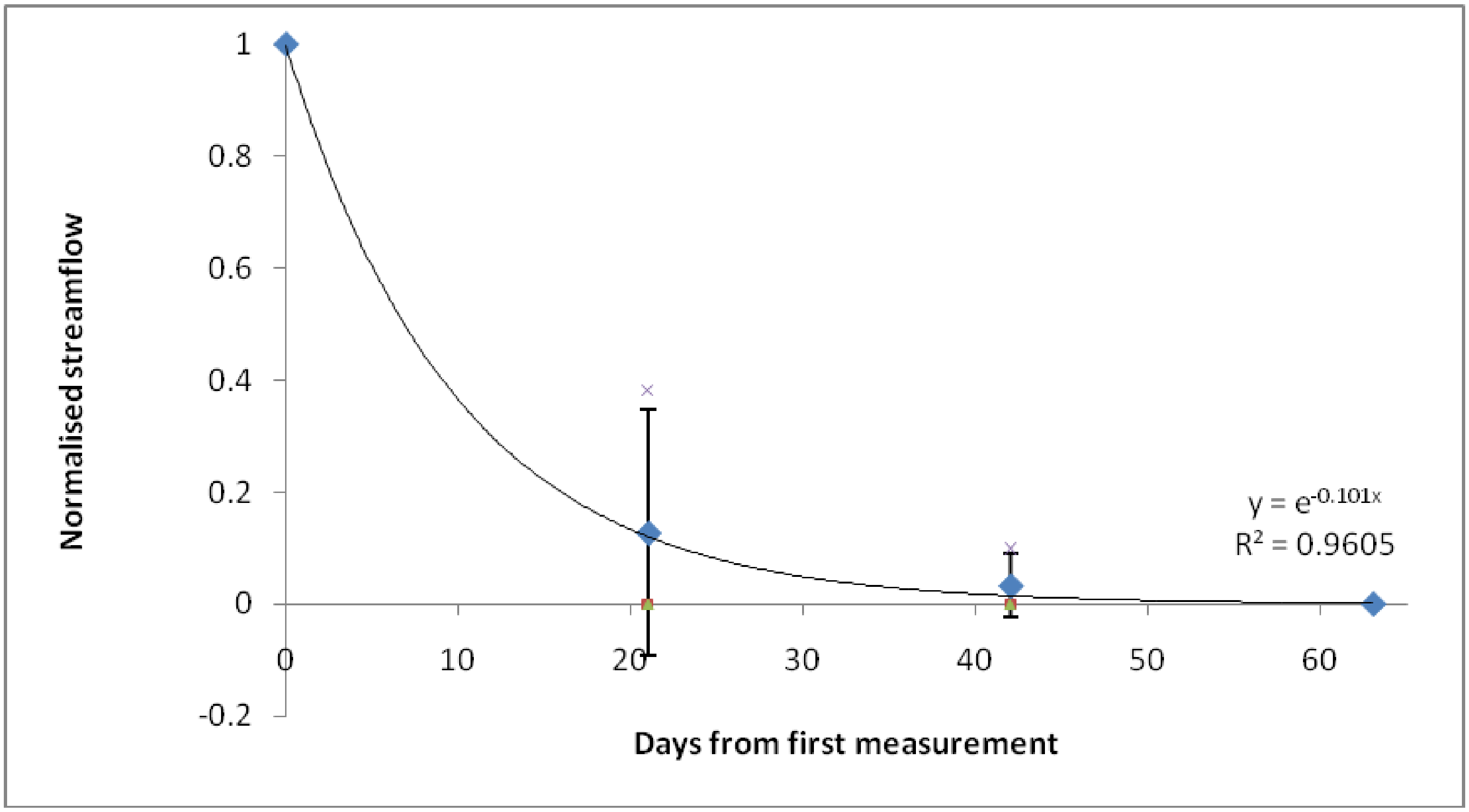

Figure 6-16: Flow characteristics of the low flow group with one standard deviation

It should be noted that the graphed trendline mainly serves for visual interpretation as the mean value of zero on day 63 makes it impossible to produce a mathematically correct exponential regression line. Therefore, the value was raised slightly above zero to provide the valuable visual impression of an approximately correct regression line.

6.2.6.6 Modelling of the high flow / low tall cover group

The three streams in this group show a linear decrease in streamflow (Figure 6-17). By the end of the dry season these streams still carried ~40% of the water they carried one month into the dry season.

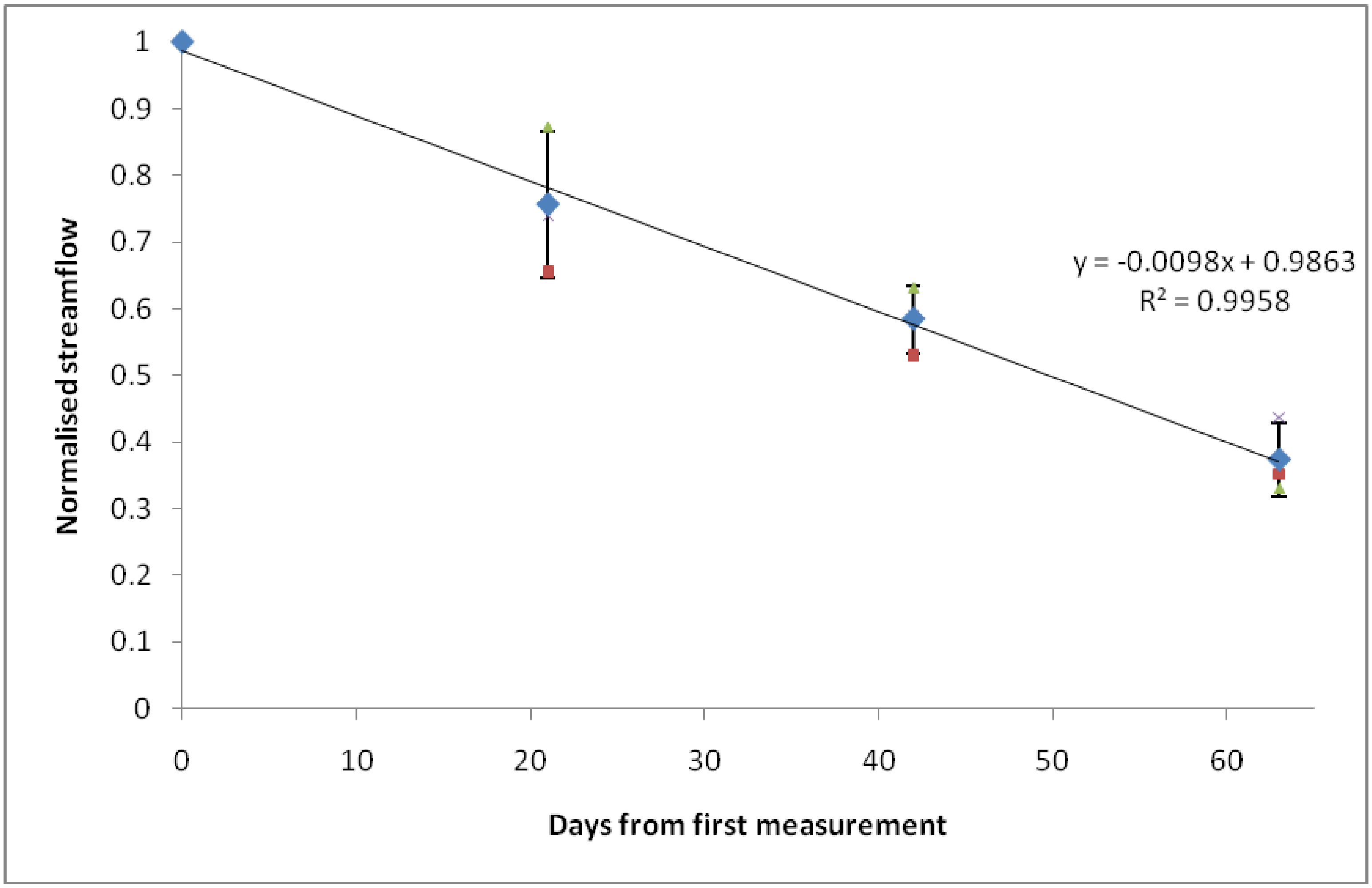

Figure 6-17: Flow characteristics of streams in the high flow / low tall cover group with one standard deviation

6.2.6.7 Modelling of the high flow / high tall cover group

All nine streams in this category show an exponential drop in streamflow (Figure 6-18). Apart from one stream, which dried up between day 42 and day 63, streams in this group drop rapidly at first and then stabilise with around ~20% of their initial flow measured one month into the dry season. Most of these streams persisted throughout the remaining dry season (observations, unquantified data).

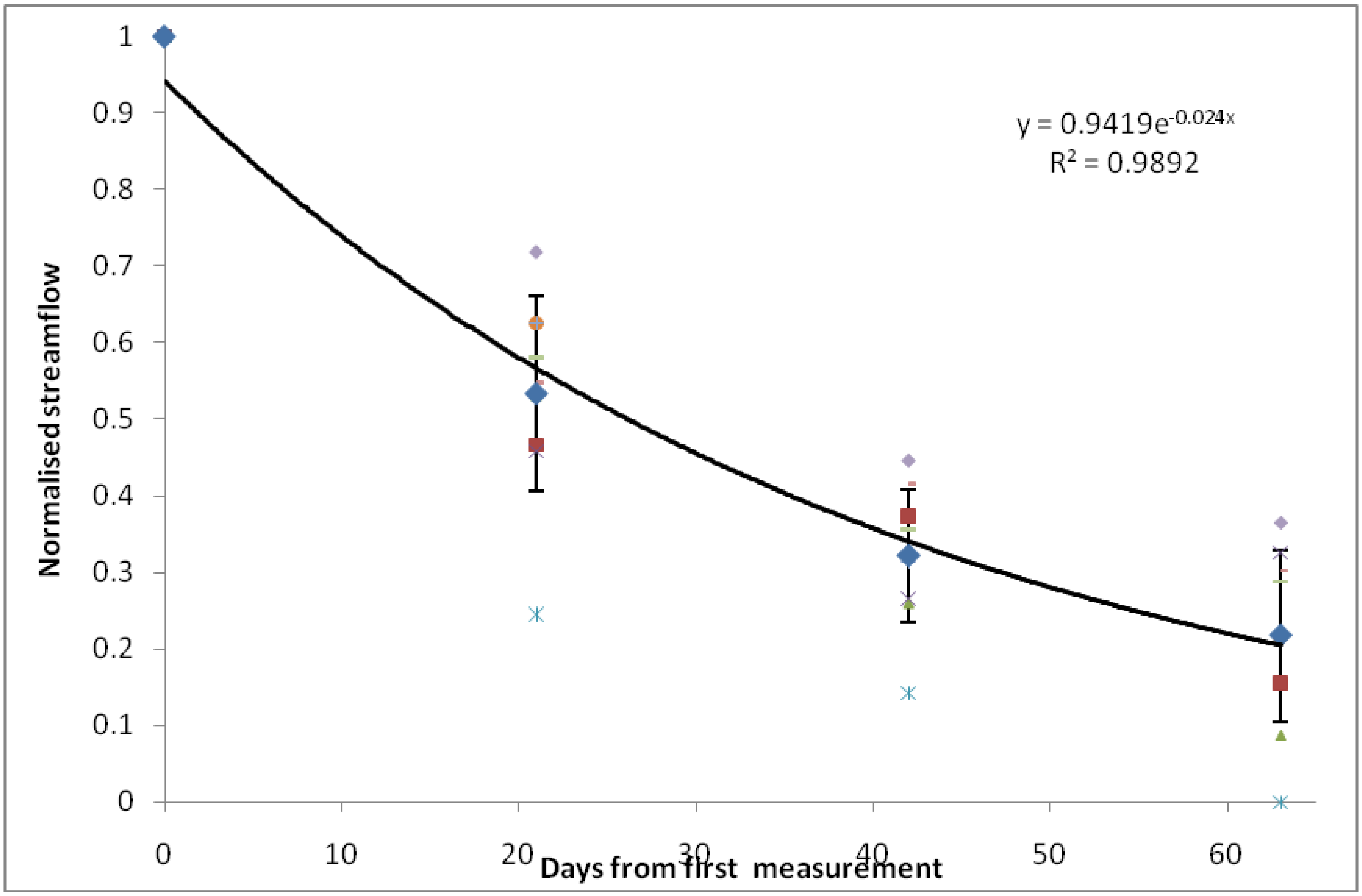

Figure 6-18: Flow characteristics of streams in the high flow / high tall cover group with one standard deviation

6.2.6.8 Comparison of the three models

When all three models are compared it becomes apparent that streams of the high flow / low cover group do not drop as rapidly as the other groups (Figure 6-19). The decline in streamflow is linear, rather than exponential. Furthermore, at the end of the dry season, streams in this category display a higher relative water discharge rate, than the other two groups. Streams in the high flow / high tall cover category drop faster than the aforementioned group, however, not as fast as streams in the low flow group. Streams in the low flow group, drop the fastest with all of them drying up during the dry season. Two of the three streams were already dry at the second measurement while the third kept flowing at a low rate for some time before drying up completely sometime between day 42 and day 63.

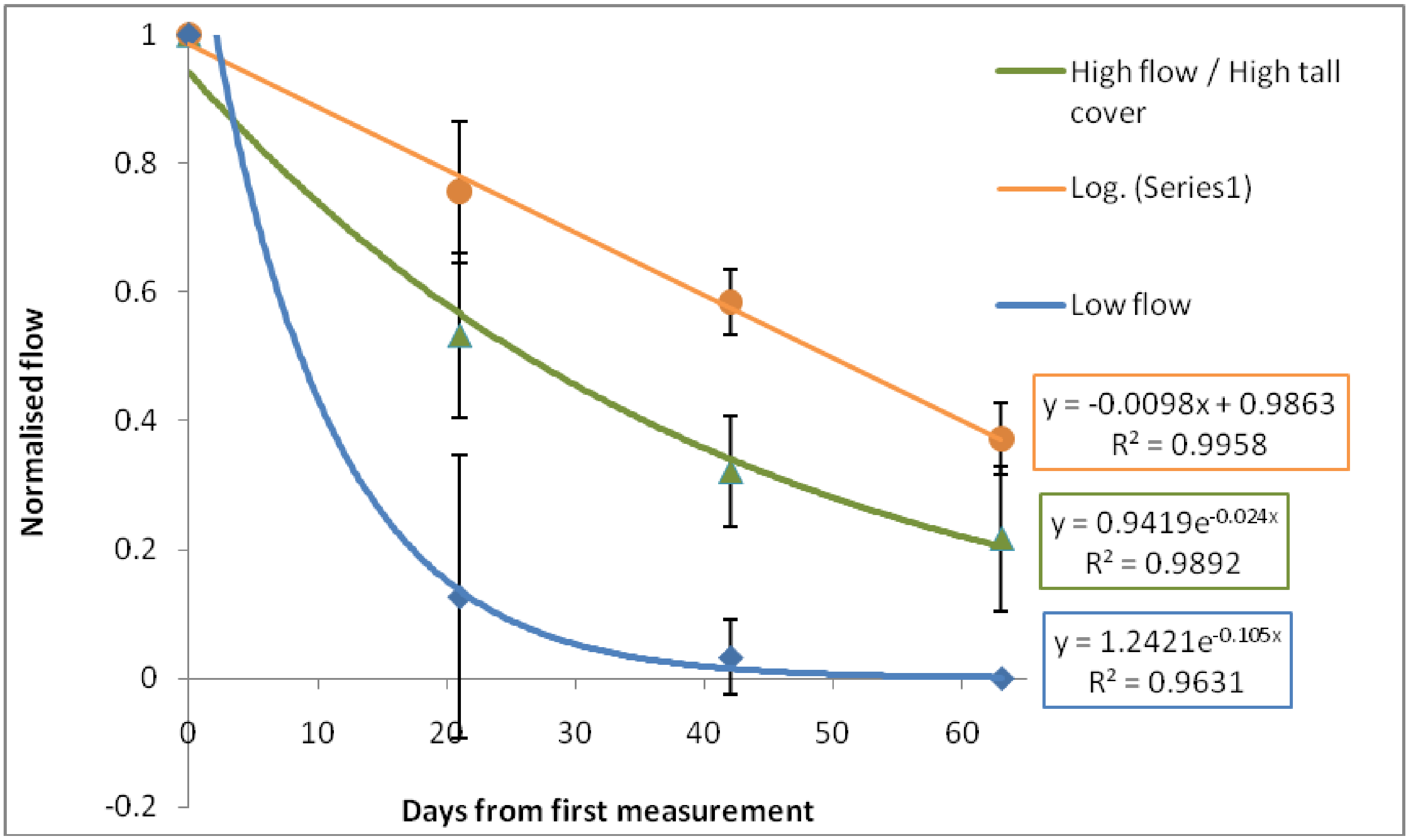

Figure 6-19: A comparison of the three models

6.2.7 Discussion

6.2.7.1 Possible reasons for non-significant results of vegetation cover

The analysis of riverine forest cover on dry season base flow showed no significant effects in the study area. A generalised linear mixed effects model was generated that could be used to predict the effect of the aforementioned factors on streamflow. With the inclusion of the statistical interaction between forest cover and day of measurement, forest cover did show a significant effect, however, in the absence of the interaction this effect was lost. This model showed only elapsed time and stream gradient as significant predictors of streamflow.

Differences in stream gradient seemed to have a large effect on the reduction in stream flow. A possible explanation for this phenomenon can be found in McGuire *et al.* (2005) who ascribe the principal determinant on base flow residence time to the effects of basin topography.

Other studies have shown that different environmental conditions can result in similar base flows. The most important of these environmental conditions are addressed here.

One aspect that has to be considered in tropical seasonally arid environments are the effects of condensation and shading. The winter (dry season) temperatures can drop as low as 12° C during the night, while daytime temperatures are usually around the 30° C mark accompanied with high solar insolation. In a situation like this shading during the day and condensation during the evening and morning hours can lead to significant evapotranspiration offset (Brauman *et al.* 2007).

Another important factor potentially offsetting evapotranspiration effects is the promotion of groundwater recharge by riparian buffers (Smakhtin 2001). As base flow during dry seasons is fed by ground water, it is a convincing argument that riparian buffers contribute greatly to sustained base flow rates in areas where the remaining watershed has a limited infiltration capability and hence, limited ground water recharge capability.

Furthermore, Gao *et al.* (2009) has shown that young/growing forests use considerably more water than old growth forests. Although average DBH/tree was measured in this experiment, which can serve as a rough estimation of average tree age, I feel that a more precise estimation of forest age is advisable. As different trees grow at different speeds and to different maximum DBHs, using average DBH/tree may be too crude a measure to gain meaningful insights into forest age.

The research presented here does not take into account possible species effects on streamflow. As mentioned in the introductory sections, different species have different water requirements and therefore it is not surprising that a streamside forest gaining much of its measured DBH circumference from fast growing species like *Eucalyptus spp*. has a different flow balance than a river that has the same total DBH composed of only slow growing trees.

In this study, watershed sizes were only calculated according to the topographic divide, however, the significance of the topographic divide on streamflow is often limited to overland flow. For low flow measurements during dry seasons, the sizes, locations and boundaries of the phreatic divides (and thus the direction of subsurface drainage) are more relevant. Unfortunately, data on phreatic divides are much less readily accessible and therefore, were unable to be used in this study.

It would be highly advisable for future studies to investigate these factors more closely, in order to create more homogenous groups of streams that only differ in riverine forest cover. If a vegetation effect is present, it is clearly not a dominant one. Therefore, controlling for these additional factors would provide a model more sensitive to the contribution of forest effects.

6.2.7.2 Methodological constraints

The study initially set out to analyse differences in the relative drop in streamflow during the dry season in streams of three different levels of riparian forest cover. As it turned out, in the course of the analysis however, neither average DBH sizes, average tree number, average DBH per tree, watershed size, riparian buffer size, nor percentage forest cover as derived from the land cover classification (chapter 3) were able to separate the streams into classes of distinct patterns of streamflow.

The fact that the model has not shown any significance of vegetation for stream flow could either represent the reality or result from the conditions under which the measurements were carried out. As relatively primitive methods were used to estimate streamflow (see section 6.2.5), the size of the introduced measuring errors may have disallowed successful separation of streamflow into different classes. In addition, the number of streams measured was possibly too small a sample size for significant differences in streamflow between different classes of forest condition to be detected.

Due to limited funds, it was not possible to take a flow meter to the field site; therefore, the streamflow had to be measured with the "float" technique. Measuring streamflow with a float is susceptible to many errors. This is especially true when measuring small streams with much turbulence and where the availability of a straight stream channel with unrestricted flow drastically limited the floating distance. Gordon *et al.* (2004) suggests measuring plots should be large enough for the float to take at least 20 seconds to cross the distance between the start and finish lines. Suitable stream reaches that met this criterion could not be found for all streams, and on some occasions the floating time was as short as 5-10 seconds. However, repeated measurements and averaging over these times was done to increase accuracy. As the drop in relative streamflow over time was the focus of this experiment, rather than accurately measuring streamflow per se, the given absolute values of streamflow should be treated with care. For future experiments, where absolute flow is to be determined, automated stream gauging, measuring streamflow with a flow meter or using the "dye" technique (Gordon *et al.* 2004) is essential.

Only naturally occurring differences in vegetation cover were measured in this study, however in many streamflow experiments, stream vegetation is manipulated and the results in streamflow recorded over the following years.

As far as I am aware, this was the first set of data collected on streamflow in this area and due to the time limitations of master’s level research, no annual streamflow data measured over several years could be obtained. This data would complement the presented dry season data and would provide a better picture of streamflow in this region.

As stream measurements took a full day to be carried out, some streams were measured in the morning while other streams were measured at noon and in the afternoon. As streamside vegetation has been shown to have a direct impact on diurnal variations in streamflow (Bren 1996), this practice could have introduced confounding errors into the flow measurements. Again this could not be avoided due to the inaccessibility of many of the stream gauging locations and the limited man-hours available. If only morning streamflow had been measured, the time difference between the first and last measured streams could have been as great as 6-7 days. This delay was judged to be too long to effectively compare streamflow across streams.

A preliminary study of the diurnal variability of streamflow in a small subset of the measured streams could have helped to gauge the relevance of this factor.

6.2.7.3 Interchangeability of forest cover variables

The difference in correlation strength between DBH/ha, the measurement of percent forest cover and trees/ha with percentage cover can be explained by the way the different variables appear on the satellite imagery. For the calculation of percentage of forest cover along the riverine buffer only the size of the canopy is visible to the satellite. The measurement DBH/ha is a function of both tree size and tree numbers, which more closely resembles the results expected from a satellite image. In addition, DBH correlates with canopy size, with thicker trees usually having larger canopies. The tree count alone potentially overestimates forest extent by including understory trees that are not visible on the satellite imagery.

6.2.7.4 Decrease of flow during the dry season

The observed patterns of decline in streamflow during the dry season is in line with the widely accepted model of streamflow in seasonally dry areas, which predicts a quick drop in stream flow after the last rainfall followed by a slower decline, approaching a minimum base flow that persists more or less unchanged throughout the rest of the dry season (Kilpatrick 1964; Nejadhashemi *et al.* 2007). My results show the base flow in the study region follows the same basic pattern.

6.2.7.5 Grouping and modelling of stream groups

The regression tree method made it possible to separate the streams into different categories. The variable best suited to split end dry season flow is flow1. This variable represents the absolute streamflow measured at the beginning of the dry season (first measurement) and signifies that if a stream is too small, it will dry up over the dry season, regardless of interactions with other biological or physical factors. Three streams were too small to persist throughout the dry season and so none of the other measured predictors were affecting these streams. This suggests that future streamflow experiments should control for stream size or at least choose streams with flow rates above 1.5 dm^3/sec.

The best suited variable to split streams of sufficient size was tall cover. This variable represents tall cover and comprises riverine forests, tall grasses and shrubland in contrast to short cover, which was defined as kikuyu grass, burnt grass, *Sporobolus* grassland and bare soil (compare chapter 3). This circumstance shows that the type of riverine vegetation in the study area has some effect on streamflow, although in this dataset it was not a dominant effect. The question whether any tall vegetation has the same effect or if forest vegetation affects streamflow differently from shrubland and tall grasses could not be resolved in this experiment.

The next best variable to group the measured streams is the stream gradient ("streamslope"). This shows that the population of measured streams varied considerably in average stream gradient. Being a significant predictor of streamflow, future studies should control for the stream gradient.

The different flow characteristics of the three separately modelled groups showed that high flow / high tall cover streams drop faster and lower than high flow / low tall cover streams. Although not significant, this could be an indication of higher water consumption in tall vegetation (due to a higher surface area) compared to short vegetation.

6.2.8 Conclusion

I set up an experiment to test whether forest cover affects stream flow. The results of this experiment showed no significant effects of any forest related measurement. While the results indicate that there is not a simple relationship between forest cover and stream flow; there are some indications that forest cover does affect stream flow (the regression tree showing forest cover as the best splitting factor to predict the final days flow percentage of high flow streams). I also found other factors that appear to be affecting stream flow including stream gradient and initial stream size, which future experiments should control for by using streams that are similar in these characteristics, or by vegetation manipulation and observing stream response through time. Nevertheless, several important recommendations for future research can be made:

- Future studies can use the remotely sensed imagery and DBH/m^2 measurements almost interchangeably due to their strong correlation.

- Future studies should be limited to streams of adequate size at the beginning of the dry season.
- Future experiments should take the effect of tall vegetation other than trees into account, given that tall cover (not measures of forest extent) proved to be the best splitting factor predicting flow at the end of the dry season.
- Future studies may yield more information, if streams exhibiting extremes of the predictor variable (forest cover) are used in the experiment, as this would facilitate the statistical testing of groups of very low forest cover and very high forest cover against each other.

No definitive answer to the question of whether the Fulani increase or decrease dry season stream flow by clearing riverine forests could be found. However, given the importance for biodiversity of this rare ecosystem and the multiple positive environmental effects of streamside vegetation, alternative solutions for riverine clearing should be sought immediately. Depending on the reasons for streamside clearing, such alternatives could be establishing more plantations (alternative source of fuel wood), establishing small scale irrigation systems (instead of river bed cultivation) or retaining some of the wet seasons' rainfall in pools or tanks for use during the dry season, for all-over better water supply during the dry season.

Chapter 7: Thesis Discussion

7.1 Discussion of thesis approach

This thesis has provided an overview of different aspects of the interactions between human and natural systems in the context of the study area. More detailed studies of each sub-system were not possible within the time and resource constraints of a master's thesis; however, this overview forms a valuable framework on which more specialised research in each individual field can be built.

Each of the four main thesis goals has been addressed in its respective section of this thesis. The land cover study gives a good indication of land cover change over the last 21 years, while also presenting an accurate account of the 2009 land cover at a high spatial resolution. The high resolution imagery used for land cover mapping serves as a baseline account of current land cover on which future forest and land cover monitoring plans can be built, hence satisfying thesis goal 1 as stated in section 1.3.

Through interviews, valuable information was gained about Fulani social structure, their cattle and pasture management strategies and environmental perspectives. The interviews were aimed at establishing and reporting facts as explained by the Fulani in order to gauge their viewpoints and generalised motivations, and can serve to help identify stakeholder groups. However, more in-depth interviews are necessary if the full effects of possible policy changes relating to natural resource access or land tenure are to be explored. Possible future conflict mediation between Fulani stakeholders and the Ngel Nyaki / Kurmin Danko conservation advocacy group within the NCF's participatory forestry framework also requires more in-depth stakeholder analysis. Nevertheless, given the limited scope of MSc level research and the limited timeframe available for fieldwork, this section adequately meets the second thesis goal as stated in section 1.3.

The information gained by researching land use to fulfil the third thesis goal (section 1.3) gives a good initial estimate of cattle stocking rates and the spatial extent of grazing. The employed method of interview and observation informed mapping of land use was fast and effective in a location for which maps of title deeds and property boundaries are non-existent or very difficult to obtain. However, more accurate land surveys are needed for the calculation of exact stocking rates and in the development of future policy decisions.

The measurement of environmental variables relevant to the Fulanis' main activity (cattle rearing), complements the information gained by interviews, observations and GIS data by providing quantitative data about factors identified as constraining cattle grazing and realisable stocking rates. The environmental data on grass productivity and streamflow presented in this thesis are indicative of current environmental conditions and quantify the decline of grass productivity and streamflow during the dry season. Further research in this area should include a more in-depth study, using data from several wet and dry seasons from which a mechanistic model of these environmental factors can be established.

Modelling the effects of different environmental factors such as the level of watershed or riverine forestation, soil compaction due to cattle trampling, frequency, timing and severity of burning, grazing, stocking rates, erosion and others on grass productivity and streamflow is an important step in devising new management strategies for sustainable development in the area. This section of the thesis (chapter 6) addressed the fourth and last thesis goal (section 1.3) and while the results of the streamflow experiments remain inconclusive, a good quantification of grass productivity decline over the dry season was achieved.

Given the extremely limited information available about Fulani activities in the study area and resulting environmental impacts, a general overview (such as this study has provided) is a valuable first step before more specialised research can be effectively focused. The size of the project placed limitations on the scope of research into each individual aspect. The extremely limited information available on the human-environmental interface of the study area presented challenges in devising an appropriate experimental setup before commencing fieldwork. With two or three field seasons these limitations could have been overcome, as the research design could have been better adapted to the local realities. However, the time limitations of master's level research and financial constraints prohibited data collection over multiple field seasons.

7.2 Discussion of results

The results of the land cover change analysis show a decrease in forest cover and an increase in grassland both outside and within the Ngel Nyaki and Kurmin Danko Forest Reserves. This conversion of forest to grasslands is most likely driven by heavy grazing and burning (especially late burning) as local pastoralists both intensify and extensify their production systems. However, a lack of awareness or incentive to change to more sustainable practices is only partially responsible for environmental degradation in the area. Pastoralists usually *do* have an awareness of the dangers of overgrazing to their livelihoods and try to avoid overgrazing by using traditional methods like sending herds on transhumance during periods of low grass productivity and periodically shifting the location of herders' huts within the cattle owner's land. These traditional methods often seem to be designed to avoid overgrazing and pasture degradation in arid and semi-arid climates, for which regions these practices were established. However, grasslands in the more temperate climate on the Mambilla Plateau may be more susceptible to degradation through overgrazing (Seastedt & Knapp 1993; Fernandez-Gimenez & Allen-Diaz 1999; Oba *et al.* 2002). Changes in the system of pastoralism practised by the Fulani from nomadic to predominantly settled pastoralism, in conjunction with increased population pressures (from human and cattle populations), mean that traditional methods to preserve rangelands have become maladaptive and are not sufficient to solve problems arising from this new lifestyle (Müller, Frank & Wissel 2007). Additional research into the possibilities for the mediation of environmental extremes (particularly the lack of fodder in the dry season) is needed to address these issues. Feasibility studies of introducing new farming methods into the study area such as haymaking, cultivating browsing crops or supplementary feeding may prove valuable. In absence of other options, increasing difficulties in obtaining grazing rights in the lowlands (due to increased population pressures of lowland pastoral groups moving into these regions) and economic considerations lead pastoralists to extend their pastures into the local Forest Reserves where they prevent succession and reduce existing closed canopy forest by burning late into the dry season (see Shono, Cadaweng & Durst 2007).

Apart from stocking rates remaining high during the dry season (when biomass production is lowest) most pastures are also frequently well overstocked during the wet season. As Davies (1946) and Lambi and Neba (2009) have demonstrated for the Jos Plateau in Nigeria and the western Cameroon Highlands, respectively, (both very similar environments to the Mambilla Plateau), average stocking rates of 118-257 cattle per ha lead to severe environmental degradation. The stocking rate on Fulani properties around Ngel Nyaki and Kurmin Danko Forest Reserves is estimated to be at the upper end of this range. It is not hard to understand that facing overgrazing on their pastures many cattle owners push their herds into the reserve, which they see as having yet unrealised grazing potential. Deforestation in favour of livestock production system extensification has been well documented in many areas the world over (Nicholson, Blake & Lee 1995; Arredondo-Leon, Munoz-Jimenez & Garcia-Romero 2008; Rudel 2008).

As recent studies have shown, a fortress conservation approach is often not successful in preventing reserve degradation from mobile actors (poachers, graziers). Intensive policing is often required to prevent these groups from exploiting the resources of reserves and parks (Bruner *et al.* 2001). Expenses for intensive policing cut deeply into the budget allocated for the protection of parks and reserves, and in the case of small protected areas such as Ngel Nyaki and Kurmin Danko (which are not expected to attract extensive income from ecotourism or other revenue generating measures) ongoing policing may not be economically feasible. Limited policing in the past and the legislation decisions that have put Ngel Nyaki and Kurmin Danko under formal protection have failed to make an impact on the actual protection of the reserves. This is predominantly because of the extent of official corruption and bribery throughout Nigeria, which enables those who can afford the bribes to disobey the law with impunity.

In addition to these practical considerations, preventing local people in developing countries from using local resources, in favour of protecting biodiversity may not be ethically and morally justifiable (Roe *et al.* 2003; Brockington 2004; Kaimowitz & Sheil 2007). Hence, the protection of small reserves using the fortress approach is not feasible (economically) and not desirable (ethically) and very likely to be unsustainable in the long run.

Furthermore, the pastoralists of the Mambilla Plateau provide a vital supply of nutrition and animal protein for a large population in an area where malnutrition is widespread. In addition, the Fulani cattle owners of the Mambilla Plateau are important economic actors (frequently providing employment, as well as a market for goods produced by agriculturalists) and as such support the economic development of the whole region. Possible changes in future policy should consider these vital roles on which the wellbeing of the whole region may well depend (see Blench 2001).

The conclusion to be drawn from this for Ngel Nyaki and Kurmin Danko Forest Reserve is that a properly planned and executed participatory approach to conservation is highly desirable. So far, the participatory approach put forward by NCF in 2006 has focused on educating the Mambilla and other farming tribes about the benefits of conservation. However, the NCF's "enlightening" strategy has apparently failed to reach Fulani herders and landowners. This is particularly unfortunate, because these are the only people that interact with the reserve on a day-to-day basis.

Already the Fulani in the study region are diversifying their livelihoods with eucalypt plantations and agriculture. Integrated landscape conservation and development should therefore, be possible to implement. It will be the challenge of locally active conservation agencies to help local Fulani to build on the already initiated transition towards sustainable livestock management and work towards conservation on a landscape scale. The Fulani residents in the study area are settled agropastoralists and enjoy relatively secure land tenure over their pastoral properties. Proponents of Hardin and his theory of "the tragedy of the commons" (Hardin 1968) would interpret this situation as potentially beneficial for sustainable management as settled Fulani families certainly have an interest in their land remaining productive and healthy. However, a lot of awareness raising and "enlightenment" must also reach the Fulani if future projects should succeed in conservation and overall land management. All awareness raising will be futile, however, if policy changes are not enacted simultaneously to create incentives for such projects. Furthermore, secure land tenure has to be guaranteed, if long term investments (like reforestation) are an objective target (see Unruh, Cligget & Hay 2005).

Rudel *et al.* (2005) and Farley (2007) describe incidences and programmes that led to successful reforestation on a landscape scale. Rudel *et al.* (2005) demonstrate two paths that lead to forest transitions: (1) either a lack of forest leads to the user groups experiencing a lack of forest products, which in turn prompts landowners or governments to plant trees in abandoned fields or (2) economic development creates enough off-farm employment that agricultural fields are abandoned (at least in marginal areas) and spontaneous encroachment of shrubs and then secondary forest occurs. Farley (2007) observed that in Ecuador, the documented forest transition was as much a result of economic development as it was seen as a means to achieve economic development. The path taken to achieve this was through government initiated reafforestation plans. In these plans landowners were paid for the labour of planting trees, and in addition were given the right to a certain percentage of the timber at the time of harvest. However, both studies agree that these forest transitions do little in preserving biodiversity, as often the areas in question are reafforested with fast growing exotic tree species, rather than native forests. This constraint could be minimised, however, if a lower profit margin was considered acceptable, and the requirement of reafforestation solely with native trees made explicit.

Under the guidelines defined in the Kyoto protocol, reafforestation could be made even more lucrative, as in addition to the revenue created through forest products, carbon credits could be sold for these plantations. The lack of investment capital or willingness to invest could be mitigated by government sponsorship of nurseries and plantations of native trees. The areas used for these plantations should first comprise marginal land, with the possibility of extending these plantations into integrated agroforestry (grazing & forestry) projects in areas better suited for grazing at a later stage. Again, secure land tenure is crucial to the success of such programmes (Richards 2000; Cacho, Marshall & Milne 2002; Jindal, Swallow & Kerr 2008; Unruh 2008).

Chapter 8: Thesis Conclusion

The forested area of Ngel Nyaki and Kurmin Danko is retreating. The status quo of a laissez-faire attitude cannot be maintained if the biodiversity of these forests is to be preserved. Autocratic exclusionary approaches are not likely to hold much promise. Therefore, for both ethical and practical reasons, a participatory approach to reserve management is desirable. This requires specific knowledge about the local actors and stakeholders in the region.

This thesis has contributed to understanding the practices and needs of one local stakeholder group: the Fulani pastoralists. For the ethical and practical reasons explained above, these stakeholders should be included in the future planning of the reserves' conservation.

Islands of protected areas are often not achieving their goal of preserving biodiversity, especially in an otherwise degraded surrounding. In such a situation, the local population and biodiversity can both benefit from a landscape conservation approach, which should be adopted in the conservation of Ngel Nyaki and Kurmin Danko Forest Reserve.

Conservation on a landscape scale, which integrates protected areas and private land, could be made viable through introducing agroforestry programs or other reforestation programs (using native species) that capitalise on timber revenues or carbon credits. The initial capital investments, however, will have to be initiated by pro-active government bodies, NGOs or the private sector.

Introducing farming methods such as haymaking, cultivating browsing crops or supplementary feeding may help to balance varying feed availability over wet and dry seasons. This would enable pastoralists to bring the process of transition to sedentarisation to a close. How each of these steps could be implemented, however, requires further research and goes beyond the scope of this thesis.

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